micropaleontology

volume 7
number 3
july 1961

Published by:

DEPARTMENT OF MICROPALEONTOLOGY
AMERICAN MUSEUM OF NATURAL HISTORY
CENTRAL PARK WEST AT SEVENTY-NINTH STREET
NEW YORK 24, NEW YORK

micropaleontology

articles

news reports

The price of this quarterly is $12.00 per year for personal subscriptions; all others, $15.00 per year. Single copies are $4.00 each.

ABSTRACT

Twenty-seven Cenomanian planktonic foraminiferal species are described and some 60 specific names included in their synonymy. These species are from North America, Europe, and an Atlantic core north of the Bahama Islands. Evidence of the planktonic foraminifera suggests a Cenomanian (rather than Turonian) age for the north Texas Eagle Ford group, an Eagle Ford (rather than Woodbine) age of the entire eastern Gulf subsurface Atkinson formation, and a mid to late Cenomanian (rather than Albian or early Cenomanian) age for the "Franciscan" strata at New Almaden, California.

The family Rotaliporidae Sigal, 1958, is recognized as distinct from the Globorotaliidae, and has been enlarged to include the subfamilies Hedbergellinae and Rotaliporinae. The Rotaliporidae have a geologic range from Hauterivian to Maestrichtian. The Planomalinidae Bolli, Loeblich and Tappan is recognized as of family rank, having been elevated from subfamily status by Sigal (1958), and the family Schackoinidae Pokorný, 1958, is also recognized as distinct from the Hantkeninidae, and has a geologic range from Aptian to Maestrichtian. The Globorotaliidae and Hantkeninidae thus are of Cenozoic occurrence.

Cretaceous planktonic foraminifera: Part I — Cenomanian

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INTRODUCTION

In a recent publication (Loeblich and others, 1957), mention was made of a plan to revise the systematics of the planktonic foraminifera. The generic revision by Bolli, Loeblich and Tappan (1957) was the first of this series, the other papers in that publication described planktonic faunas from selected strata and localities.

The present article is the first of a series revising the Cretaceous planktonic species. This series will discuss the species both from a stratigraphic and morphologic viewpoint, and thus describe the species according to their geologic occurrence as related to the European stages.

The Cenomanian stage was studied first for a number of reasons. A large percentage of the genotype species of Cretaceous planktonic genera occur in the Cenomanian, and a study of their geographic and geologic occurrence was considered of prime importance. Furthermore, because of the difference in time of orogeny and stratigraphic breaks in mid-Cretaceous time, controversies had arisen as to the Early or Late Cretaceous age of many of these strata, and, therefore, as to their interregional and world-wide correlations. It was hoped that a study of the planktonic species would resolve certain of these stratigraphic problems. In addition, a relatively lengthy period of past studies of the mid-Cretaceous strata of the Gulf Coast and elsewhere by the writers made this a logical place for beginning these Cretaceous planktonic studies. Independent studies by various specialists in the past had led to the use of a different set of specific names in many different areas for the same species, although too wide specific limits in other cases obscured the stratigraphic values of the foraminifera. As a result of the present revision, many of the Cenomanian species are now known to have a far wider geographic extent and more limited stratigraphic range than was previously believed.

THE CENOMANIAN PLANKTONIC SPECIES

In the revision of the planktonic foraminifera by Bolli, Loeblich and Tappan (1957), all genera of the families Hantkeninidae, Orbulinidae (now = Globigerinidae, ICZN ruling, Opinion 552), Globorotaliidae and Globotruncanidae then known were redescribed and refigured on the basis of their type species. Some 56 described genera were discussed, and 32 recognized as valid. In the four years since that publication appeared, some 15 additional genera have been proposed by these and other authors. Some of these newer genera are here recognized, and other revisions are included.

The almost explosive increase in interest in the planktonic foraminifera in recent years is attested to by the fact that only one-fourth of the 71 genera that have been described to date were known a dozen years ago, at the time of the last edition of Cushman's textbook on the foraminifera (1948). Only one of the eight genera herein recognized for the Cenomanian planktonic species was described when the writers began their studies of Cenomanian foraminifera some two decades ago.

In the four years that have elapsed since the publication of our planktonic revision (Bolli, Loeblich and Tappan, 1957) other revisions and discussions of these forms have appeared, including those by Morozova (1957), Pokorný (1958), Reiss (1957, 1958), Sigal (1958), and Banner and Blow (1959). Both the increase in the number of specialists concerned with this group of foraminifera and the increase in the number of publications now appearing about the planktonic species, are extremely encouraging, for only by a concerted attack can the previous relative neglect of this group be rapidly overcome. The flood of publications concerned with planktonic Foraminifera, issued during the past few years, has resulted in a rapidly changing taxonomy. Some of these changes have been at the family, subfamily, generic, and subgeneric levels, and have been discussed in papers on classification. Many revisions have also been made at the specific level in recent years, and examination of Cenomanian material from many areas has shown that many additional changes are necessary.

As was noted in the above-mentioned planktonic revision, many of the early descriptions and illustrations (and unfortunately some later ones also) are too generalized, inaccurate or incomplete for precise species delineation. Thus, time after time, new species, which were poorly described or incorrectly assigned generically in one area, were later described under different names in other areas. This has been particularly true of the Greenhorn fauna described by Morrow (1934), as most of the species he described have been given different names in European and north African studies, as well as in California.

The planktonic species are relatively variable in certain respects, and insufficient allowance for individual variation within a species has also tended to multiply the taxonomic confusion. "Species" have been described for different growth stages, small specimens given one name and large or gerontic individuals given another name. Failure to recognize an alternation of generations has also resulted in the use of one name for what is apparently the megalospheric generation, and another name for the microspheric forms. Examination of a large suite of specimens of any planktonic species will demonstrate the relatively great amount of size variation within the population. Separate species, varieties, or subspecies have been recognized for various extremes within such a population, with no geographic or stratigraphic basis for such separation, even though complete gradational sequences could be selected between these extremes. Subspecies are not here recognized for extremes within a single population, for the term subspecies should be used in paleontology in the zoological sense – only when there is some degree of isolation in time or space. A multiplicity of names for members of a local population can serve no geological or zoological purpose, and can only complicate the taxonomy and thereby retard the use of these valuable forms.

In the present article, some 60 specific names have been discussed and included in the 27 recognized and illustrated species. The remainder have been placed in synonymy. Many of the species are thus observed to have a far wider geographic range than was previously known, and their increased value in correlation will certainly offset any possible inconvenience in the use of fewer taxonomic units. The rules of priority have been followed strictly in this regard.

In contrast to the wide "splitting" of certain species of planktonic foraminifera, other groups have suffered from an opposite treatment, or "lumping." This has resulted from inaccurate and generalized earlier descriptions, which could not be augmented by reference to type specimens or topotypes. An excellent example is shown by *Globigerina cretacea* d'Orbigny, described originally from the lower Campanian White Chalk of St. Germain, near Paris. In the past century, nearly every publication on Cretaceous foraminifera, and many on Tertiary and even Recent foraminifera, has referred some specimens to this "species," including forms that would now be placed in *Globotruncana*, *Hedbergella*, *Globorotalia* and *Globigerina*, thus completely eliminating any stratigraphic value of this "species." After the present manuscript had been completed, a publication by Banner and Blow appeared, in which a lectotype was designated for *Globigerina cretacea* d'Orbigny, showing this species to belong to the genus *Globotruncana* (Banner and Blow, 1960). Selection of a lectotype now places the species *Globigerina cretacea* on a firm basis, and should aid considerably in the task of future morphologic and geologic delineation of the Cretaceous planktonic species. A comment concerning the designation of this lectotype appears indicated. Banner and Blow stated that "In the material which is extant in the d'Orbigny collections deposited in the Museum National de l'Histoire Naturelle, Paris, only one tube of specimens remains which has this locality (St. Germain) marked upon it in Terquem's handwriting; these must constitute the only available syntypic series. Six specimens were present of which two were broken, the others had infilled umbilici and only one test was clean and empty and corresponded with the original d'Orbigny illustration. This specimen has been selected and isolated as lectotype..." It appears that the material in the vial from which Banner and Blow selected the lectotype may have also included material from another locality or from a later date than the original publication, for d'Orbigny's original description stated (1840, p. 34) "Nous n'en avons qu'un seul exemplaire

de Saint-Germain, et plusieurs d'Angleterre." This should not affect the lectotype designation, however, and the specimen selected by Banner and Blow appears similar to the original figure and description. The very large umbilical aperture was noted by d'Orbigny, who also commented, "On remarque une seconde ouverture, peut-être accidentelle, à la troisiéme loge." This is a further indication of the *Globotruncana* nature of the species, as the previous apertures were left uncovered by the destruction of the tegilla, which normally cover the broad open umbilicus. Specimens previously referred to *Globigerina cretacea*, in the Cenomanian strata, are here placed in *Hedbergella delrioensis* (Carsey), *H. brittonensis*, new species, *H. amabilis*, new species, and *Clavihedbergella simplex* (Morrow). They can now be separated both morphologically and stratigraphically, and thus become more useful.

Because of the large number of synonyms and different generic combinations considered in the present study, an index to Cenomanian species is given. The first use of each specific name and each subsequent different generic combination are given, with a notation as to which of the 27 currently recognized species it concerns. Some species are noted, but are neither described nor referred to another described species, as no material was available to the writers, and recognition or reassignment solely on the basis of the literature was believed unwise.

Anomalina bentonensis Morrow, 1934 = *Globigerinelloides bentonensis* (Morrow).
A. breggiensis Gandolfi, 1942 = *Globigerinelloides breggiensis* (Gandolfi).
A. eaglefordensis Moreman, 1927 = *Globigerinelloides eaglefordensis* (Moreman).
A. lorneiana d'Orbigny of Gandolfi, 1942 = *Hedbergella trocoidea* (Gandolfi).
A. lorneiana var. *trocoidea* Gandolfi, 1942 = *Hedbergella trocoidea* (Gandolfi).
A. roberti Gandolfi, 1942 = *Ticinella roberti* (Gandolfi).
Biticinella breggiensis (Gandolfi) Sigal = *Globigerinelloides breggiensis* (Gandolfi).
Clavihedbergella moremani (Cushman).
C. simplex (Morrow).
Globigerina almadenensis Cushman and Todd, 1948 = *Hedbergella trocoidea* (Gandolfi).
G. aumalensis Sigal, 1952. Not seen, appears to be *Praeglobotruncana stephani* (Gandolfi).
G. cretacea d'Orbigny of Moreman, 1927 = *Hedbergella amabilis* Loeblich and Tappan, new species.
G. cretacea d'Orbigny of Morrow, 1934 = *Hedbergella brittonensis* Loeblich and Tappan, new species.
G. cretacea d'Orbigny of Tappan, 1940, 1943 = *Hedbergella delrioensis* (Carsey).
G. cretacea d'Orbigny of Gandolfi, 1942. Not seen.
G. cf. *G. cretacea* d'Orbigny of Applin, 1954 = *Hedbergella brittonensis* Loeblich and Tappan, new species.
G. cretacea d'Orbigny var. *delrioensis* Carsey, 1926 = *Hedbergella delrioensis* (Carsey).
G. delrioensis Carsey of Frizzell, 1954 = *Hedbergella delrioensis* (Carsey).
G. gaultina Morozova, 1948. Not seen, referred to *Ticinella* by Subbotina, 1953.
G. gautierensis Bronnimann, 1952 = *Hedbergella delrioensis* (Carsey).
G. globigerinelloides Subbotina, 1949 = *Hedbergella planispira* (Tappan).
G. graysonensis Tappan, 1940 = *Gubkinella graysonensis* (Tappan).
G. infracretacea Glaessner, 1937. Not seen.
G. paradubia Sigal, 1952. Not seen.
G. planispira Tappan, 1940 = *Hedbergella planispira* (Tappan).
G. portsdownensis Williams-Mitchell, 1948 = *Hedbergella portsdownensis* (Williams-Mitchell).
G. subdigitata Carman of Noth, 1951. Not seen.
Globigerinella aequilateralis (Brady) of Gandolfi, 1942. Not seen.
G. aissana Sigal, 1952. Not seen.
G. escheri clavata Bronnimann, 1952. Not seen.
G. tururensis Bronnimann, 1952. Not seen.
G. ultramicra Subbotina, 1949. Not seen.
Globigerinelloides bentonensis (Morrow).
G. eaglefordensis (Moreman).
Globorotalia almadensis Cushman and Todd, 1948 = *Rotalipora evoluta* (Sigal).
G. californica Cushman and Todd, 1948 = *Praeglobotruncana stephani* (Gandolfi).
G. cushmani Morrow, 1924 = *Rotalipora cushmani* (Morrow).
G. decorata Cushman and Todd, 1948 = *Rotalipora greenhornensis* (Morrow).
G. delrioensis Plummer, 1931 = *Praeglobotruncana delrioensis* (Plummer).
G. delrioensis Plummer of Tappan, 1940 = *Rotalipora evoluta* (Sigal).
G. greenhornensis Morrow, 1934 = *Rotalipora greenhornensis* (Morrow).
G. marginaculeata Loeblich and Tappan, 1946 = *Praeglobotruncana delrioensis* (Plummer).
G. ? multiloculata Morrow, 1934 = *Ticinella multiloculata* (Morrow).
G. ? multiloculata Morrow of Mallory, 1959 = *Globorotalia* sp., not *Ticinella multiloculata* (Morrow).
G. subconica Morrow, 1934 = *Globorotalites subconicus* (Morrow), not planktonic.
G. ? youngi Fox, 1954 = *Hedbergella planispira* (Tappan).
Globotruncana alpina Bolli, 1945. Not seen.
G. appenninica O. Renz, 1936 = *Rotalipora appenninica* (O. Renz).
G. (Rotalipora) apenninica O. Renz of Reichel, 1950 = *Rotalipora appenninica* (O. Renz).
G. apenninica O. Renz var. α Gandolfi, 1942 = *Rotalipora balernaensis* Gandolfi.
G. (Rotalipora) apenninica O. Renz var. *alpha* Gandolfi of Reichel, 1950 = *Rotalipora balernaensis* Gandolfi.
G. apenninica cf. α Gandolfi of Bolli, 1951 = *Rotalipora appenninica* (O. Renz).
G. (Rotalipora) apenninica apenninica (O. Renz) of Küpper, 1955 = *Rotalipora evoluta* Sigal.
G. (Rotalipora) apenninica O. Renz subsp. *balernaensis* Gandolfi, 1957 = *Rotalipora balernaensis* Gandolfi.
G. apenninica O. Renz var. β Gandolfi, 1942 = *Praeglobotruncana stephani* (Gandolfi).
G. apenninica O. Renz var. γ Gandolfi, 1942 = *Rotalipora reicheli* Mornod.
G. (Rotalipora) apenninica O. Renz subsp. *globotruncanoides* Sigal of Gandolfi, 1957 = *Rotalipora greenhornensis* (Morrow).
G. apenninica O. Renz forma *typica* Gandolfi, 1942 = *Rotalipora appenninica* (O. Renz).
G. (Rotalipora) apenninica Renz var. *typica* Gandolfi of Mornod, 1950 = *Rotalipora appenninica* (O. Renz).

G. (Rotalipora) appenninica O. Renz var. *typica* Gandolfi of Bolli, in Church, 1952 = *Rotalipora evoluta* Sigal.
G. (Rotundina) aumalensis (Sigal) of Küpper, 1955 = *Praeglobotruncana stephani* (Gandolfi).
G. benacensis Cita, 1948 = *Rotalipora benacensis* (Cita).
G. (Thalmanninella) brotzeni Sigal of Mornod, 1950 = *Rotalipora greenhornensis* (Morrow).
G. (Rotundina) californica (Cushman and Todd) of Küpper, 1955 = *Ticinella aprica* Loeblich and Tappan, new species.
G. (Rotalipora) evoluta Sigal of Reichel, 1950 = *Rotalipora evoluta* Sigal.
G. (Rotalipora) globotruncanoides Sigal of Küpper, 1955 = *Rotalipora greenhornensis* (Morrow).
G. helvetica Bolli, 1945. Not seen.
G. kuepperi Thalmann, 1959 = *Praeglobotruncana stephani* (Gandolfi).
G. (Rotalipora) montsalvensis Mornod, 1950 = *Rotalipora cushmani* (Morrow).
G. (Rotalipora) montsalvensis var. *minor* Mornod, 1950. Not seen.
G. renzi Gandolfi of Bolli, 1945. Not seen.
G. (Praeglobotruncana) renzi (Thalmann and Gandolfi) subsp.
G. primitiva Küpper, 1956 = *Praeglobotruncana stephani* (Gandolfi).
G. (Rotalipora) reicheli Mornod, 1950 = *Rotalipora reicheli* Mornod.
G. (Ticinella) roberti (Gandolfi) of Reichel, 1950 = *Ticinella roberti* (Gandolfi).
G. stephani Gandolfi, 1942 = *Praeglobotruncana stephani* (Gandolfi).
G. stephani Gandolfi of Mornod, 1950 = *Praeglobotruncana delrioensis* (Plummer).
G. (Rotundina) stephani stephani Gandolfi of Küpper, 1955 = *Praeglobotruncana stephani* (Gandolfi).
G. stephani Gandolfi var. *turbinata* Reichel = *Praeglobotruncana stephani* (Gandolfi).
G. (Praeglobotruncana) stephani (Gandolfi) subsp. *turbinata* Reichel of Küpper, 1956 = *Praeglobotruncana stephani* (Gandolfi).
G. ticinensis Gandolfi, 1942. Not seen.
G. (Thalmanninella) ticinensis Gandolfi of Reichel, 1950. Not seen.
G. (Thalmanninella) ticinensis subticinensis Gandolfi, 1957. Not seen.
G. ticinensis ticinensis Gandolfi of Cita, 1948. Not seen.
G. (Rotalipora) turonica Brotzen of Reichel, 1950 = *Rotalipora cushmani* (Morrow).
G. (Rotalipora) turonica var. *expansa* Carbonnier, 1952. Not seen.
G. n. sp. indet. Küpper, 1956 = *Rotalipora greenhornensis* (Morrow).
G. (Thalmanninella) sp. of Küpper, 1955 ≟ *Rotalipora greenhornensis* (Morrow).
Hantkenina cenomana (Schacko) of Cushman and Wickenden, 1930 = *Schackoina cenomana* (Schacko).
H. multispinata Cushman and Wickenden, 1930 = *Schackoina multispinata* (Cushman and Wickenden).
H. trituberculata Morrow, 1934 = *Schackoina multispinata* (Cushman and Wickenden).
Hastigerinella moremani Cushman, 1931 = *Clavihedbergella moremani* (Cushman).
H. moremani Cushman, 1931 (Part) = *Clavihedbergella simplex* (Morrow).
H. simplex Morrow, 1934 = *Clavihedbergella simplex* (Morrow).
H. simplicissima Magné and Sigal, 1954 = *Clavihedbergella simplex* (Morrow).
Hastigerinoides rohri Bronnimann, 1952 = *Schackoina cenomana* (Schacko).
H. simplicissima (Magné and Sigal) of Banner and Blow, 1959 = *Clavihedbergella simplex* (Morrow).
Hedbergella amabilis Loeblich and Tappan, new species.
H. brittonensis Loeblich and Tappan, new species.
H. delrioensis (Carsey).
H. hiltermanni Loeblich and Tappan, new species.
H. planispira (Tappan).
H. portsdownensis (Williams-Mitchell).
H. trocoidea (Gandolfi).
H. washitensis (Carsey).
Hedbergina seminolensis (Harlton) of Bronnimann and Brown, 1956 = *Hedbergella trocoidea* (Gandolfi).
Planomalina? almadenensis Cushman and Todd, 1948 = *Planomalina buxtorfi* (Gandolfi).
P. apsidostroba Loeblich and Tappan, 1946 = *Planomalina buxtorfi* (Gandolfi).
P. buxtorfi (Gandolfi).
P. caseyi Bolli, Loeblich and Tappan, 1957 = *Globigerinelloides eaglefordensis* (Moreman).
P. escheri (Kaufman) of Bolli, 1959. Not seen.
P. tururensis (Bronnimann) of Bolli, 1959. Not seen.
Planulina buxtorfi Gandolfi, 1942 = *Planomalina buxtorfi* (Gandolfi).
P. eaglefordensis (Moreman) of Cushman, 1940 = *Planulina kansasensis* Morrow, 1934. Not planktonic.
P. greenhornensis (Morrow) of Cushman, 1940 = *Rotalipora greenhornensis* (Morrow).
Praeglobotruncana delrioensis (Plummer).
P. delrioensis (Plummer) of Bronnimann and Brown, 1956 (part) = *Praeglobotruncana stephani* (Gandolfi).
P. (Hedbergella) delrioensis (Carsey) of Banner and Blow, 1959 = *Hedbergella delrioensis* (Carsey).
P. delrioensis (Plummer) var. *turbinata* (Reichel) of Bronnimann and Brown, 1956 = *Praeglobotruncana stephani* (Gandolfi).
P. gautierensis (Bronnimann) of Bolli, 1959 = *Hedbergella delrioensis* (Carsey).
P. modesta Bolli, 1959 = *Hedbergella planispira* (Tappan).
P. planispira (Tappan) of Bolli, Loeblich and Tappan, 1957 = *Hedbergella planispira* (Tappan).
P. (Clavihedbergella) simplex (Morrow) of Banner and Blow, 1959 = *Clavihedbergella simplex* (Morrow).
P. stephani (Gandolfi).
P. (Praeglobotruncana) stephani (Gandolfi) of Banner and Blow, 1959 = *Praeglobotruncana stephani* (Gandolfi).
P. (Praeglobotruncana) cf. *P. stephani* (Gandolfi) of Banner and Blow, 1959 = *Praeglobotruncana delrioensis* (Plummer).
P. (Hedbergella) trocoidea (Gandolfi) of Banner and Blow, 1959 = *Hedbergella trocoidea* (Gandolfi).
Rotalipora appenninica (O. Renz).
R. appenninica (O. Renz) of Subbotina, 1953 = *Rotalipora appenninica* (O. Renz), in part, and = *Rotalipora greenhornensis* (Morrow) in part.
R. cf. *R. appenninica* (O. Renz) of Bolli, Loeblich and Tappan, 1957 = *Rotalipora evoluta* Sigal.
R. appenninica (O. Renz) var. *typica* (Gandolfi) of Ayala, 1954 = *Rotalipora appenninica* (O. Renz).
R. balernaensis Gandolfi.
R. benacensis (Cita).
R. brotzeni (Sigal) of Bolli, Loeblich and Tappan, 1957 = *Rotalipora greenhornensis* (Morrow).
R. cushmani (Morrow).
R. cushmani (Morrow) var. *evoluta* Sigal, 1948 = *Rotalipora evoluta* Sigal.
R. evoluta Sigal.

R. globotruncanoides Sigal, 1948 = *Rotalipora greenhornensis* (Morrow).
R. greenhornensis (Morrow).
R. reicheli Mornod.
R. roberti (Gandolfi) of Bolli, Loeblich and Tappan, 1957 = *Ticinella roberti* (Gandolfi).
R. turonica Brotzen, 1942 = *Rotalipora cushmani* (Morrow).
R. turonica subsp. *thomei* Hagn and Zeil, 1954. Not seen.
Rotundina stephani (Gandolfi) of Subbotina, 1953 = *Praeglobotruncana stephani* (Gandolfi).
Rugoglobigerina multiloculata (Morrow) of Bermudez, 1952 = *Ticinella multiloculata* (Morrow).
Schackoina bicornis Reichel of Bykova, Vasilenko, Voloshinova, Miatliuk and Subbotina, 1959 = *Schackoina multispinata* (Cushman and Wickenden).
S. cenomana (Schacko).
S. cenomana bicornis Reichel, 1947 = *Schackoina multispinata* (Cushman and Wickenden).
S. gandolfi Reichel, 1947 = *Schackoina cenomana* (Schacko).
S. sp. cf. *S. gandolfi* Reichel of Küpper, 1956 = *Clavihedbergella simplex* (Morrow).
S. moliniensis Reichel, 1947 = *Schackoina multispinata* (Cushman and Wickenden).
S. multispinata (Cushman and Wickenden).
S. primitiva Tappan.
S. pustulans pustulans Bolli, 1959. Not seen.
S. pustulans quinquecamerata, 1959. Not seen.
S. trituberculata (Morrow) of Loetterle, 1937 = *Schackoina multispinata* (Cushman and Wickenden).
Siderolina cenomana Schacko, 1896 = *Schackoina cenomana* (Schacko).
Thalmanninella brotzeni Sigal, 1948 = *Rotalipora greenhornensis* (Morrow).
T. greenhornensis (Morrow) of Bronnimann and Brown, 1956 = *Rotalipora greenhornensis* (Morrow).
T. manaurensis Sigal of Gandolfi, 1955, not seen (species attributed to Sigal in range chart).
T. multiloculata (Morrow) of Bronnimann and Brown, 1956 = *Ticinella multiloculata* (Morrow).
Ticinella alpha (Reichel) of Banner and Blow, 1959 (for *Globotruncana*) *(Thalmanninella) ticinensis* var. *alpha* Gandolfi of Reichel, 1950 and for *Globotruncana ticinensis* var. α Gandolfi, 1942). Name *alpha* invalid as not proposed as new subspecies or variety by Reichel or Gandolfi = synonym of *Globotruncana ticinensis subticinensis* Gandolfi, 1957.
T. aprica Loeblich and Tappan, new species.
T. multiloculata (Morrow).
T. roberti (Gandolfi).

CENOMANIAN STRATIGRAPHIC PROBLEMS

Location of the Lower—Upper Cretaceous boundary

Age dating and correlation of strata near the Lower—Upper Cretaceous boundary has proven difficult in many areas. Some part of this difficulty has doubtless arisen because the Lower—Upper Cretaceous boundary in Europe and the major stratigraphic break in North America were not concurrent. The separation between Early and Late Cretaceous in Europe is between the Albian and Cenomanian stages, whereas the boundary between the Comanche and Gulf series of the Gulf Coast and Caribbean area lies within the European Cenomanian stage. The Albian—Cenomanian boundary is within the Washita group in Texas, and within the Gautier formation in Trinidad, and the gradation between these stages is sufficiently close that there has been considerable controversy concerning the exact boundary placement. Similarly, in the western interior, California, etc., the beds in this stratigraphic position have been variously considered as Lower or Upper Cretaceous.

We are following the usage of the U. S. Geological Survey (Cobban and Reeside 1952, p. 1014) in separating the Lower and Upper Cretaceous at the Albian—Cenomanian boundary, and thus regard the Cenomanian strata discussed here as the basal Upper Cretaceous, although some (Grayson and Maness) formations are referrable to the otherwise Early Cretaceous Comanche series.

Basis for zonations within the Cretaceous

In the past, zonation of the American Cretaceous has been based almost exclusively on megafossils, and numerous ammonite or *Inoceramus* faunal zones have been proposed (Cobban and Reeside, 1952; Imlay, 1944; Stephenson, King, Monroe and Imlay, 1942). Because of the different Cretaceous depositional embayments, the varied depositional environments, and the present discontinuous outcrops, other groups had generally proved less useful. Benthonic foraminifera are an example of this, for very few diagnostic species have been found common to the different geographic regions, although some attempts at interregional correlation have been made on the basis of benthonic species. For nearly two decades European micropaleontologists and stratigraphers have zoned the Cretaceous by means of the planktonic foraminifera, but only in recent years have such attempts been made in the western hemisphere. Such planktonic species as have been described have generally been included in general microfaunal studies, and regarded as of no more than average interest. Some of the species were originally generically misidentified, so that for years their planktonic nature was unsuspected. Many of these species had been given different names in different areas, and only by a study of type material could the synonymy be proved. Although much still remains to be learned, the present study again demonstrates the value of planktonic foraminifera in correlation, and the nearly world-wide occurrence of many of these species.

Faunal provinces

In the present seas, planktonic foraminifera are of nearly world-wide occurrence, the major difference in the faunas being latitude-controlled, probably due to the temperatures. The same feature is noted for earlier planktonic faunas, and some species appear to be restricted to the warmer seas, although others are cosmopolitan in occurrence. In the mid-Cretaceous, faunal differences may be observed between the planktonic assemblages of the Tethyan provinces and those of the Boreal region.

Relatively complete Cenomanian sequences occur in the northern and Tethyan faunal provinces in Europe, but the planktonic faunas have been described in greater detail from the Tethyan areas. Tethyan faunas are also reported from North Africa. In the American Gulf Coast, the Cenomanian deposits are also of the Tethyan faunal province, but unfortunately the midportion of the Cenomanian in that region consists of near-shore and even nonmarine deposits, and contains no planktonic species.

Among the Tethyan planktonic species, *Planomalina buxtorfi* (Gandolfi) occurs in California, Texas, north Africa, and Switzerland, in uppermost Albian, and lower Cenomanian strata, but apparently does not occur in northern Europe, or in the western interior of the United States. *Hedbergella washitensis* (Carsey) and *Praeglobotruncana delrioensis* (Plummer) are similarly geographically restricted early Cenomanian species. *Clavihedbergella moremani* (Cushman) is a late Cenomanian Tethyal form.

In contrast to the few geographically somewhat restricted planktonic species, many of the species of *Rotalipora*, *Schackoina*, *Globigerinelloides* and *Hedbergella* range more widely. These latter species are of great value in age dating, and, as discussed below, suggest that some previous age designations and correlations were erroneous.

Availability of material

A proven accurate and detailed zonation requires complete stratigraphic coverage of sampling from a number of areas. Unfortunately, this is difficult to obtain for the Cenomanian in the Western Hemisphere. One of the best areas might appear to be the Gulf Coast, where sedimentation was nearly continuous from Albian through Cenomanian. There are excellent planktonic faunas in the lower Cenomanian (Grayson and Maness) formations but the overlying Woodbine formation is a near-shore to nonmarine sand or shale, from which no planktonic foraminifera have been obtained. The upper Cenomanian Eagle Ford group also has numerous planktonic species, but an important part of the mid-Cenomanian sequence is missing. Similarly, in most of the western interior, planktonic faunas are relatively rare, and many of the strata contain none, although other strata could almost be termed a fossil "*Globigerina*" ooze. Possibly, a more complete Cenomanian section will eventually be obtained in California, but here surface weathering of many outcrops has destroyed faunas to a considerable depth, and detailed surface collecting or coring is needed.

PLANKTONIC FORAMINIFERA AND CENOMANIAN STRATIGRAPHY

Cenomanian planktonic species supply evidence for accurate age dating and correlation of strata in many areas, and may be used in solving some of the local stratigraphic problems.

Gulf Coast

In Texas and Oklahoma, there is a gradational contact between the Albian and Cenomanian strata. The Main Street formation, of late Albian age, is followed conformably by the lower Cenomanian Grayson formation. The majority of benthonic species of foraminifera found in the upper Albian beds range upward into the Grayson as well, and a few of the planktonic species also cross this boundary. Because of this faunal similarity, the Grayson was formerly considered to be of late Albian age (Tappan, 1940). However, evidence of the planktonic foraminifera, like that of the ammonites, shows this formation to belong to the lowest Cenomanian.

Planomalina buxtorfi (previously known in this region as *P. apsidostroba* Loeblich and Tappan) occurs in Texas in the Main Street and underlying Paw Paw formations, both of Albian age, but does not range upward into the Grayson. In some other areas, notably Switzerland, North Africa and California, it ranges from Albian into lower Cenomanian strata. Some late Albian holdovers do occur in the lower Cenomanian Grayson formation, including *Hedbergella washitensis* (Carsey), *H. delrioensis* (Carsey) and *H. planispira* (Tappan), *Globigerinelloides eaglefordensis* (Moreman) and *Praeglobotruncana delrioensis* (Plummer). In addition, the Cenomanian species *Rotalipora evoluta* Sigal first appears in the Grayson, as does the extremely rare *Schackoina primitiva* Tappan.

In central Texas and in the subsurface of north Texas, the Grayson formation is overlain by the Buda limestone. Planktonic species have not yet been isolated from this hard limestone. In the subsurface, the Maness formation overlies the Buda, having been removed from the present outcrop areas by later erosion. In this subsurface Maness formation, *Rotalipora appenninica* (O. Renz) was found to occur with *Hedbergella planispira* (Tappan), *H. delrioensis* (Carsey), *H. washitensis* (Carsey), and *Praeglobotruncana delrioensis* (Plummer).

The Woodbine sand, considered by Stephenson and others (1942) to represent most of the Cenomanian, unconformably overlies the Grayson, Buda, and Maness formations. Largely near-shore or nonmarine in origin, it contains very few foraminifera and no planktonic species.

The Eagle Ford shale, overlying the Woodbine sand, was considered by Stephenson and others (1942) to be largely Turonian in age, with only the lower *Acanthoceras*-bearing beds regarded as uppermost Cenomanian. Moreman (1942) recognized five megafossil zones in the Eagle Ford shale, one equivalent to the Tarrant formation, two in the Britton formation, and two in the Arcadia Park shale. He regarded the Tarrant as upper Cenomanian, the Britton as lower Turonian, and the Arcadia Park as upper Turonian. The same species were noted to occur in the Britton formation as in the Greenhorn limestone, and Moreman stated that the upper part of the Graneros shale probably was

equivalent to the lower Britton. The Hartland shale member of the Greenhorn is of late Graneros age; hence, the lower Britton formation would be considered to be equivalent to the Hartland shale.

Adkins and Lozo (1951) regard the lower Britton formation as Cenomanian, and the upper Britton and Arcadia Park shale as Turonian. We agree with the local correlations of these formations, and the equivalency of the Hartland and Eagle Ford shales, but believe that the correlation with the standard European section is too high. The planktonic fauna of the Britton clay includes numerous species in common with the fauna of the Hartland shale, and, in addition, contains *Praeglobotruncana stephani* (Gandolfi) and *Schackoina cenomana* (Schacko). These two species occur in middle to upper Cenomanian strata in Europe and north Africa as well as in California. The Britton fauna also includes the long-ranging *Hedbergella planispira* (Tappan) and *Globigerinelloides eaglefordensis* (Moreman), which occur widely in both Albian and Cenomanian strata. Both the Britton and Arcadia Park formations appear to be of late Cenomanian age, as no exclusively Turonian elements are present in the planktonic fauna.

A foraminiferal faunule, described by Applin (1955) from the subsurface lower Atkinson formation of the southeastern Gulf region, was said to be of Woodbine age. This formation, in Alabama, Georgia, and Florida contained "specimens of species characteristic of the Washita group, in addition to a few species that range from the lower to the middle part of the Gulf series, and some species that were described from, and presumably restricted to, beds of Woodbine age" (Applin 1955, p. 190). The planktonic foraminiferal evidence suggests that this is too low an age assignment for the Atkinson formation. The longer ranging benthonic foraminifera might perhaps imply a Woodbine age, but planktonic forms such as *Rotalipora cushmani* (Morrow), *Clavihedbergella moremani* (Cushman), *C. simplex* (Morrow), and *Hedbergella brittonensis*, new species, point to an Eagle Ford and lower Greenhorn equivalency (upper Cenomanian). Furthermore, the benthonic foraminifera from the "Barlow fauna" of the Atkinson appear more closely related to an Eagle Ford assemblage than to any known Woodbine fauna. This is rather indirect evidence as known Woodbine foraminiferal faunas are from such restricted environments that they are composed almost wholly of agglutinated species. Such Woodbine assemblages are therefore difficult to compare to normal marine assemblages of agglutinated and abundant calcareous specimens (including many planktonic ones) such as occur in the Atkinson formation. Neither the Woodbine nor Eagle Ford faunas are as yet thoroughly known, having been largely neglected in favor of the more abundantly fossiliferous younger Cretaceous strata of the region. There is thus an environmentally caused absence of planktonic species in the Woodbine strata of the western Gulf, but the occurence of the above-mentioned planktonic species in the eastern Gulf Atkinson formation, as well as in the Eagle Ford (Britton clay) and Greenhorn (Hartland shale), strongly suggests a middle or late Cenomanian age for the Atkinson.

Blake Plateau submarine core

A submarine core from the Blake Plateau, north of the Grand Bahama Island (Lamont Geological Observatory Core A 167–25), was taken below the edge of the plateau on the escarpment. This core was erroneously recorded by Ericson, Ewing and Heezen (1952, p. 489) as 110 cm. in length, but it actually totaled 175 cm. Taken at 28°52′ N. latitude and 76°47′ W. longitude, it was from a depth of 955 fathoms. The location is shown on the map of figure 3 of Ericson, Ewing and Heezen (1952). The core was then reported to be "Cretaceous, and probably Lower Cretaceous." The benthonic foraminifera in this core include some species typical of outcropping strata ranging from the Trinity (lower Albian) through Fredericksburg and Washita (Albian-Cenomanian) in the Gulf Coast. The planktonic species include the cosmopolitan and relatively long-ranging *Hedbergella washitensis* (Carsey), *H. planispira* (Tappan), *Globigerinelloides bentonensis* (Morrow), *G. eaglefordensis* (Moreman), and *Praeglobotruncana delrioensis* (Plummer), all of which occur in both uppermost Albian and lower Cenomanian strata. However, the geologically more restricted species which are present, such as *Rotalipora greenhornensis* (Morrow), suggest the placement of this cored section in the middle Cenomanian. The cored strata are older than the geographically close Atkinson formation, and although the core contains many species in common with the Grayson and Maness formations of Texas, it seems probable that it is more nearly of Woodbine age (post-Maness and pre-Eagle Ford).

Trinidad

In Trinidad, Bronnimann (1952) and Bolli (1951, 1957, 1959) have described the planktonic assemblages from the Cenomanian and other Cretaceous stages. Bolli (1957, fig. 10) divided the Albian-Cenomanian Gautier formation into the following zones, in ascending order: *Rotalipora ticinensis ticinensis* (upper Albian-basal Cenomanian), *Globigerina washitensis*, and *Rotalipora appenninica appenninica* zones, (both lower to middle Cenomanian).

In 1959, Bolli (chart 1) listed the same three faunal zones for the Gautier, as merely "Cenomanian." With no indication of missing section, this might imply that the zones were here regarded as representing the entire Cenomanian. In view of the ranges of the same species elsewhere, even the ages given in the 1957 paper seem somewhat high. *Planomalina* cf. *P. apsidostroba* Loeblich and Tappan (= *P. buxtorfi* (Gandolfi)) was recorded by Bolli (1959) as occurring in the *Praeglobotruncana rohri* zone of the Maridale formation, regarded as middle Albian in age and equivalent to the Fredericksburg group of the Gulf Coast. In Texas, *P. buxtorfi* is an excellent marker for the uppermost Albian Paw

Paw and Main Street formations of the upper Washita group, and this species does not even occur in the four lower Washita formations which are immediately above the Fredericksburg group. In California, Cuba, and southern Europe, it also ranges upward into the lower Cenomanian. *Hedbergella washitensis*, regarded as a mid-Gautier zone fossil by Bolli, is characteristic of the Washita group (middle to upper Albian) on the Gulf Coast. It also ranges upward into the lower Cenomanian Grayson, Del Rio, and Maness formations. In north Africa it also occurs in lowest Cenomanian. Thus, to regard this zone in Trinidad as late lower to mid-Cenomanian also seems too high. Bolli also noted the rarer occurrence of *H. washitensis* in the overlying *R. appenninica* zone.

It seems probable that the Albian-lower Cenomanian section in Trinidad is quite thick, as in Texas, and the Gautier and possibly the upper Maridale formations appear equivalent to the Washita group. The *Hedbergella washitensis* zone should be regarded as of middle to late Albian age, and only the superjacent *Rotalipora appenninica appenninica* zone (with rare *G. washitensis*) is of early Cenomanian age. Middle and upper Cenomanian faunules appear to be absent, or as yet undiscovered, in the complex geological framework of Trinidad. Certainly many faunal zones are absent in Trinidad between the *Rotalipora appenninica appenninica* zone and the overlying Turonian *Globotruncana inornata* zone of Bolli.

Western Interior

Few Cenomanian planktonic species are known in the western interior, other than those from the lower Greenhorn limestone. Morrow (1934) included planktonic species in his description of foraminifera and ostracodes from the Graneros, Greenhorn, Carlile, and Niobrara strata. Of these, the Graneros shale and the Lincoln and Hartland members of the Greenhorn limestone are regarded by the U. S. Geological Survey as Cenomanian in age (Cobban and Reeside, 1952). Only "*Globigerina cretacea*" was recorded from the Graneros shale by Morrow, and this species and two species of *Guembelina* were reported from the Lincoln. The Hartland shale had a distinctive fauna with a large number of planktonic species, referred by Morrow to *Guembelina*, *Hantkenina*, *Globigerina*, *Hastigerinella*, *Globorotalia* and *Anomalina*. Many of these have been virtually ignored in the ensuing years and only recently recognized as of nearly world-wide occurrence. At the present time every one of Morrow's planktonic species has been reallocated generically, due to the extensive revisions of this group of foraminifera. The Hartland shale was regarded as uppermost Cenomanian by Cobban and Reeside (1952). In it occur the species *Globigerinelloides bentonensis* (Morrow), *Rotalipora cushmani* (Morrow), *R. greenhornensis* (Morrow), *Ticinella multiloculata* (Morrow), *Clavihedbergella simplex* (Morrow), and *Schackoina multispinata* (Cushman and Wickenden), all widely ranging and characteristic late Cenomanian species. Fox (1954) described a few species from the Greenhorn limestone, as well as others from the Carlile and Cody formations of South Dakota and Wyoming. He reported the planktonic species *Globigerina cretacea* d'Orbigny, *Guembelina moremani* Cushman, *Globorotalia? youngi* Fox, *Guembelina pseudotessera* Cushman (only in the upper Greenhorn), and *Globorotalia cushmani* Morrow. *Globorotalia? youngi* Fox is here regarded as a synonym of the long-ranging upper Albian-Cenomanian *Hedbergella planispira* (Tappan). Of the remaining species, only *Rotalipora cushmani* (Morrow) is restricted within the Cenomanian, and it has world-wide occurrence in upper Cenomanian deposits.

California

The California Cenomanian, although not yet well known faunally, represents perhaps the best opportunity to study the time ranges of foraminiferal species in a continuous section. Material studied by the writers represents the middle and late Cenomanian. More detailed study of this important area would do much to clarify the overlapping ranges of planktonic species. It is important to note that California Cretaceous planktonic species are identical to those occurring in the western interior, Gulf Coast, western Europe, and the Caribbean, and do not represent a provincial fauna such as has so often been attributed to California. Although some of the California Cenomanian foraminifera had been described as "new" species in California, in reality they were already known by other names elsewhere in America and Europe, and their California names are synonyms.

Foraminifera were described from "Franciscan" strata near New Almaden, California, and considered to be from the Lower Cretaceous (Cushman and Todd, 1948, p. 91). Glaessner (1949) referred some of these same species to "*Anomalina*" *roberti* Gandolfi (= *Ticinella*) and *Globotruncana ticinensis* Gandolfi, and, on the basis of the occurrence of these and other species, regarded the strata as of Albian age. Küpper (1955) stated that these above-mentioned species did not occur at New Almaden, but that *Planomalina buxtorfi* (Gandolfi) and *Globotruncana (Rotundina) californica* (Cushman and Todd) indicated an Albian to lower Cenomanian age. The other indigenous planktonic species were said to range from lower to middle Cenomanian, and he regarded the strata as "early or medial Cenomanian in age."

The characteristic species of the earliest Cenomanian have not been observed in these strata at New Almaden, and the planktonic species which do occur include *Planomalina buxtorfi*, *Hedbergella trocoidea*, *Rotalipora greenhornensis*, and *Praeglobotruncana stephani*, all of which (except *P. buxtorfi*) are characteristic of later Cenomanian strata in Kansas (lower Greenhorn limestone), Texas (Eagle Ford shale), the eastern Gulf Coast, the Atlantic submarine core, North Africa, Germany,

Switzerland, Spain, and Italy. The New Almaden strata would, therefore, appear to be of middle to late Cenomanian age.

The strata from the Sacramento Valley included in this study contain *Rotalipora cushmani*, *R. greenhornensis*, *Praeglobotruncana stephani* and *Schackoina cenomana*, and are also of middle to upper Cenomanian age.

Africa

There seems to be much difference of opinion as to the stratigraphic limits of species in the Algerian-Tunisian Cretaceous. In the literature, characteristic upper Cenomanian forms are recorded with typically lower Cenomanian species. *Rotalipora cushmani* (Morrow), originally described from the upper Cenomanian Hartland shale member of the Greenhorn limestone, is recorded as occurring with *Globigerina washitensis* Carsey, *Rotalipora evoluta* Sigal, etc. in Algeria. In North America and in other parts of the world, *R. cushmani* does not occur with lower Cenomanian forms, but is restricted to the upper Cenomanian. It seems possible that such atypical occurrences may, in part, be due to recognition of wider specific limits, or, in part, to misunderstanding of the species.

Dubourdieu and Sigal (1949) described the Cretaceous strata from Algeria (Ouenza region), recording many planktonic species from the Albian and Cenomanian strata. In a later paper, the age zonation was modified somewhat so that, as corrected, the upper Vraconian beds contain *Globigerina washitensis*, *G. planispira*, *Globigerinella cushmani*, "*Anomalina*" *roberti*, *Planulina buxtorfi*, *Globotruncana ticinensis typica*, *G. stephani*, *G. apenninica*, and *Rotalipora* n. sp. The lower Cenomanian contains *Globigerina washitensis*, *Globotruncana ticinensis typica*, *G. stephani*, *G. apenninica* β, *Rotalipora turonica*, *R. cushmani*, *R. globotruncanoides*, and *Thalmanninella brotzeni*. Mid-Cenomanian species include *G. stephani*, *G. apenninica* β, *Rotalipora turonica*, *R. cushmani*, *R. globotruncanoides*, and *Thalmanninella brotzeni*. The upper Cenomanian has *Globotruncana ticinensis typica*, *G. stephani*, *G. turona*, *Rotalipora cushmani*, *R. globotruncanoides* and *Thalmanninella brotzeni*. In general, this zonation agrees well with that of the United States, and the nearly identical ranges of *Rotalipora cushmani* and *R. turonica* might confirm their synonymy here as do those of *R. globotruncanoides* and *Thalmanninella brotzeni*.

In a later publication on the Algerian section, Sigal (1952, p. 25) arbitrarily placed the base of the Cenomanian at the first appearance of *Rotalipora appenninica*, but stated that macropaleontologists would regard these strata as being Vraconian (= latest Albian) in age. According to Sigal, the lower Cenomanian contains the last *Planulina buxtorfi*, a continued occurrence of *Globigerina washitensis* and *Thalmanninella ticinensis*, the first appearance of *T. brotzeni*, *Rotalipora globotruncanoides*, *R. reicheli*, *R. cushmani* and *R. turonica*, the last two persisting in the upper Cenomanian. Although, in 1948, Sigal defined *Rotalipora cushmani* var. *evoluta* as occurring in the lowest Cenomanian, with *Globotruncana ticinensis*, *Globigerina washitensis*, and *Textularia rioensis*, he did not mention it in the 1952 publication.

In Tunisia, Dalbiez (1955, p. 162) recorded *Rotalipora cushmani* in the upper Cenomanian, and noted that forms with a tendency to uncoil, as shown by the strongly protruding last chamber, correspond to the original description of *R. cushmani* var. *evoluta* Sigal. He considered the Tunisian specimens as variants of *R. cushmani*. We have recognized *R. evoluta* as a valid species, occurring only in the lower Cenomanian and not in association with *R. cushmani*. Numerous specimens of *Rotalipora cushmani* show this tendency to uncoil, but they are unrelated to the species described by Sigal as *R. evoluta*. Dalbiez (1955, chart 1) recorded *R. appenninica appenninica* and *R. appenninica alpha* in the lower Cenomanian; *R. appenninica typica* and *Thalmanninella brotzeni* in the middle Cenomanian; and *Thalmanninella brotzeni*, *R. cushmani*, *R. reicheli*, *Globotruncana stephani turbinata*, and *R. cushmani evoluta* in the upper Cenomanian.

On the basis of the literature, therefore, there seems to be a fair correlation between the early Cenomanian planktonic faunas of Algeria and Tunisia and those of North America, and between the North African late Cenomanian and the equivalent strata in the western hemisphere. The middle Cenomanian fauna is less well defined.

Sigal (1956) recorded Albian and Cenomanian planktonic species from the subsurface of Madagascar. He found *Globigerina washitensis* Carsey in the lower strata (regarded as Albian), and reported *Ticinella roberti* (Gandolfi), *Biticinella breggiensis* (Gandolfi), and *Ticinella gaultina* Morozova in the younger strata. Later, *Thalmanninella ticinensis* (Gandolfi) appeared, and was followed by *Planomalina buxtorfi* (Gandolfi) and *Rotalipora appenninica* (Renz). The last species signified the base of the Cenomanian. Mid-Cenomanian strata contained *Thalmanninella brotzeni* Sigal and *Rotalipora cushmani* (Morrow). Sigal also noted the presence of *Rugoglobigerina*, with characteristic ornamentation, although this genus is commonly found only in younger strata. Possibly these ornamented Cenomanian forms belong to the ornate *Hedbergella hiltermanni*, n. sp., which lacks the umbilical tegilla characteristic of the genus *Rugoglobigerina*.

Banner and Blow (1959) record *Rotalipora globotruncanoides* Sigal, *Hedbergella* sp., *Ticinella roberti* (Gandolfi), and *Praeglobotruncana (Praeglobotruncana)* cf. *stephani* (Gandolfi) from the subsurface Cenomanian of Tanganyika.

Western Europe

In northern Spain, in the Allin Valley of Navarra, Colom (1952) described the faunas of the Cenomanian and Turonian strata. The lower Cenomanian is sandy

and lacks a planktonic fauna. Mid-Cenomanian strata were reported to contain *Globigerina planispira*, *G. washitensis*, and *Globotruncana (Globotruncana) stephani*; the upper Cenomanian contains *Globigerina washitensis*, *G. planispira*, *Globotruncana (Globotruncana) stephani*, *G. (Rotalipora) apenninica*, and *G. (R.) cushmani*, *G. (Thalmanninella) brotzeni*, and *G. (R.) montsalvensis* (the last-named was from either the uppermost Cenomanian or lower Turonian). Turonian species included *G. (T.) brotzeni*, *G. (R.) helvetica*, *G. (G.) imbricata*, *G. (Ticinella) roberti*, and *Globigerina planispira*.

Certain of these forms would now be differently allocated, but exact specific determinations cannot be made solely from the published descriptions and figures, without examination of the material. The illustrated *Globigerina planispira* is much larger than is characteristic of this species; hence, this form undoubtedly represents one of the other species of *Hedbergella*. The specimens illustrated as *Ticinella roberti* appear far too strongly keeled, and even bicarinate. As this species was reported to occur in the Turonian in Spain (rather than in the lower Cenomanian where the species typically occurs), it seems probable that the strongly bicarinate form illustrated represents a true *Globotruncana* rather than *Ticinella* or *Rotalipora*.

In southeastern Spain, near Caravaca, Murcia province, the complete Upper Cretaceous sequence is almost entirely in a pelagic facies (Busnardo, Durand Delga, Fallot and Sigal, 1957; and Fallot, Durand Delga, Busnardo, and Sigal, 1958). The lowest strata contain "*Globotruncana* gr. *stephani* Gandolfi, *Rotalipora appenninica* Renz sp., *R. evoluta* Sigal, *Thalmanninella brotzeni* Sigal. *Th. greenhornensis* Morrow" . . . and large Globigerinas. In the present usage, these would probably be *Praeglobotruncana stephani*, *Rotalipora appenninica*, *R. evoluta*, and *R. greenhornensis*. These large Globigerinas doubtless also represent one of the species of *Hedbergella*. The higher strata were reported to contain *Globigerina* gr. *paradubia* Sigal, *Globotruncana stephani* Gandolfi (= *Praeglobotruncana*), *Rotalipora globotruncanoides* Sigal (= *R. greenhornensis*), *R. cushmani* (Morrow), *Thalmanninella brotzeni* (= *R. greenhornensis*), and *T. greenhornensis* (Morrow) (= *Rotalipora*). These species and those in the lower strata were regarded as indicating a middle and late Cenomanian age.

Cenomanian planktonic foraminifera have been studied in detail in Switzerland. Perhaps the best known section is that of the gorge of the Breggia River in Canton Ticino. The contact between the Albian (Vraconian) and Cenomanian is here placed near the middle of the Scaglia bianca (bed 35), where "*Thalmanninella*" *ticinensis* is supplanted by *Rotalipora appenninica*. Important zone fossils in this section are *Planomalina buxtorfi*, occurring in the middle Scaglia bianca, and ranging from the upper Albian into the lowest Cenomanian beds, and *Praeglobotruncana stephani* and *R. appenninica*, ranging from upper *Scaglia bianca* through the *Scaglia rossa* and into the Flysch.

From Montsalvens, Switzerland, Mornod (1950) recorded the species *R. appenninica* in the middle-upper Cenomanian, and *R. reicheli*, *Thalmanninella brotzeni* (= *R. greenhornensis*), and *R. montsalvensis* (= *R. cushmani*) in the upper Cenomanian. In addition, Mornod records the latter as occurring "just to" the Santonian, where two isolated specimens were found. This latter record seems doubtful, inasmuch as *R. cushmani* has not been recorded this high elsewhere.

Noth (1951) recorded *Schackoina cenomana*, "*Thalmanninella*" *ticinensis*, *Rotalipora appenninica*, *R. reicheli*, and *R. montsalvensis* (= *R. cushmani*) from Austria, but did not zone their occurence within the Cenomanian. In Bavaria, Hagn and Zeil (1954) recorded *R. appenninica* in the upper Cenomanian and lower Turonian strata; *R. globotruncanoides* (= *R. greenhornensis*), *R. reicheli*, and *R. turonica* (= *R. cushmani*) from the Cenomanian-lower Turonian; *R. montsalvensis* (= *R. cushmani*) from upper Cenomanian—Santonian; *R. cushmani* from upper Cenomanian; and *Globotruncana stephani* (and var. *turbinata*) (= *Praeglobotruncana*) from the upper Cenomanian to lower Turonian.

Ziegler (1957) described the foraminiferal fauna of the Cenomanian of the region of Sulzbach, in northern Bavaria. In the lower part of the Oberer Grunsandstein, he recorded *Praeglobotruncana delrioensis* (Plummer), which he considered as including *P. stephani* (Gandolfi) and *P. delrioensis* (Plummer) var. *turbinata* (Reichel). These are undoubtedly true *P. stephani* (Gandolfi), as *P. delrioensis* is found only in lower Cenomanian strata. In the uppermost Cenomanian strata recorded, the Eybrunner Mergel, Ziegler reported *Globigerina cretacea* d'Orbigny, *Rotalipora cushmani* (Morrow), and *P. delrioensis* (here considered as *P. stephani*), and regarded these as indicating the upper Cenomanian.

In northern Germany, *Hedbergella planispira*, *Schackoina cenomana*, and *Rotalipora greenhornensis* are here recorded from the *Inoceramus crippsi* and *Schloenbachia varians* zones of the Cenomanian and *R. reicheli* from the *I. crippsi* zone.

Russia

In Russia, Subbotina (1949) reported *Globigerina globigerinelloides* Subbotina (= *Hedbergella planispira* (Tappan)) from Aptian to Albian strata, and *Globigerinella ultramicra* Subbotina from mid-Albian to Turonian strata (the type specimen was from the Cenomanian). The upper Albian and Cenomanian were combined into a single zone characterized by *Guembelina* (= *Heterohelix*), *Guembelitria cenomana* Keller, single-keeled *Globotruncana* (probably *Rotalipora*), and radiolarians.

In 1953, Subbotina recorded from Russia *Globigerina globigerinelloides*, *Globigerinella ultramicra*, *Schackoina cenomana*, *Ticinella gaultina* (Morozova), *Rotalipora appenninica* (O. Renz), *R. reicheli* Mornod, and *Rotundina stephani* (Gandolfi) (= *Praeglobotruncana*). This assem-

blage would seem to indicate an upper Cenomanian age when compared to equivalent ranges in North America.

DISPOSITION OF TYPES

All primary types and figured specimens are deposited in the U. S. National Museum, Washington, D. C.

SYSTEMATIC DESCRIPTIONS

Family **Planomalinidae** Bolli, Loeblich and Tappan, 1957

Planomalininae Bolli, Loeblich and Tappan, 1957, U. S. Nat. Mus., Bull., no. 215, p. 21.
Planomalinidae Bolli, Loeblich and Tappan. – Sigal, 1958, Soc. Géol. France, C. R. Somm., no. 11–12, p. 263.

Type genus: Planomalina Loeblich and Tappan, 1946.

Coiling planispiral; chambers spherical, ovate, clavate or angular rhomboid; primary aperture equatorial or symmetrically paired, with umbilical portions of successive apertures remaining as relict secondary apertures.

Originally defined as a subfamily of the family Hantkeninidae, because of the similarity of these groups in the planispiral coiling and equatorial aperture, the Planomalinidae was regarded as of family rank by Sigal (1958, p. 263) because of the different stratigraphic ranges of the group of genera of which it is composed. The most important distinction is the presence of relict apertures and their bordering lips in the Planomalinidae. *Schackoina* is not here included (as was done by Banner and Blow, 1959, p. 9) because of the absence of relict apertures. Their statement that *Schackoina* has imperforate portici (lips) and weak relict apertures is not upheld by an examination of a large number of well-preserved specimens.

Genus **Globigerinelloides** Cushman and ten Dam, 1948

Globigerinelloides Cushman and ten Dam, 1948, Cushman Lab. Foram. Res., Contr., vol. 24, p. 42.
Biticinella Sigal, 1956, Soc. Géol. France, C. R. Somm., no. 3, p. 35. (Type species: *Anomalina breggiensis* Gandolfi, 1942. Fixed by original designation and monotypy.)

Type species: Globigerinelloides algeriana Cushman and ten Dam, 1948. Fixed by original designation and monotypy.

Test free, planispiral, biumbilicate, involute to partially evolute, lobulate in outline; chambers rounded to ovoid, may be somewhat elongated in specimens tending to become evolute; sutures depressed, radial, straight to curved or sigmoid; wall calcareous, finely perforate, radial in structure, surface smooth or roughened; aperture a broad, low, interiomarginal equatorial arch, with lateral umbilical portions of successive apertures remaining open as relict apertures.

Remarks: Only the somewhat evolute forms were included in this genus by Bolli, Loeblich and Tappan (1957), and the involute species were regarded as belonging to *Planomalina* Loeblich and Tappan. The latter genus is now restricted to include only keeled species, and the simple species without poreless margin are here placed in *Globigerinelloides*. *Biticinella* Sigal was previously considered a possible synonym of *Planomalina*, but is now regarded as a synonym of *Globigerinelloides* as it also lacks a keel.

Globigerinelloides bentonensis (Morrow)
Plate 2, figures 8–10

Anomalina bentonensis Morrow, 1934, Jour. Pal., vol. 8, no. 2, p. 201, pl. 30, fig. 4a–b. – Cushman, 1940, Cushman Lab. Foram. Res., Contr., vol. 16, p. 28, pl. 5, fig. 3a–b. – Cushman, 1946, U. S. Geol. Survey, Prof. Paper, no. 206, p. 154, pl. 63, fig. 7a–b.

Test free, planispiral, involute to partially evolute, biumbilicate, six to eight chambers in the final whorl, increasing gradually in size, early chambers closely appressed, later less appressed and tending to become evolute, peripheral outline lobulate; sutures distinct, radial, constricted, straight to gently curved; wall calcareous, finely perforate, surface finely spinose, especially in the earlier chambers of the last whorl, the final few chambers nearly smooth; aperture a broad low interiomarginal, equatorial arch, bordered above by a narrow lip, the lateral portions of the previous apertures and lips remaining uncovered by later chambers, so that relict supplementary apertures are preserved around the umbilical region.

Topotype of figure 9 is 0.37 mm. in maximum diameter, and 0.21 mm. in thickness. Other specimens range in maximum diameter from 0.21 to 0.41 mm.

Remarks: Described originally as an *Anomalina*, the planktonic nature of this species was long unsuspected. Neither the original description nor figures indicate the presence of relict apertures, and in fact the original description stated "aperture peripheral, passing onto the dorsal side." This was somewhat misleading, as the test was stated to be "nearly symmetrical, ... earlier whorls partly exposed on both sides at the center," and thus would not seem to show a differentiation into dorsal (spiral) and ventral (umbilical) sides. When numerous Greenhorn specimens were observed to be referrable to *Globigerinelloides*, the holotype of *Anomalina bentonensis* was re-examined. Both the holotype and the numerous topotypes show all the generic characters of *Globigerinelloides*. Sigal (1956, p. 36) suggested that *Anomalina breggiensis* might be a synonym of *A. bentonensis* Morrow, because of similar external appearance, but that additional study would be required in order to be certain of the synonymy. *Anomalina breggiensis* was made the type species of *Biticinella* Sigal, which is here regarded as a synonym of *Globigerinelloides*. In the absence of topotype material, we have not included *A. breggiensis* in the present synonymy.

Globigerinelloides bentonensis is apparently more evolute than *G. breggiensis*. Similar species have been referred to *Globigerinella aspera* (Ehrenberg), but the types of the latter appear to have fewer chambers per whorl, and they may not even be planispiral. *Globigerinella aissana* Sigal, from the Cenomanian of North Africa, may be synonymous with this species, but no relict apertures were figured and the limited description mentions neither the spinose surface, relict apertures, nor the tendency to become evolute, all characteristic of the present species. *Globigerinelloides bentonensis* (Morrow) differs from *G. eaglefordensis* (Moreman) in being larger, more inflated and less evolute.

This species was originally described from the Greenhorn limestone (upper Cenomanian), but has a relatively long geologic range for a planktonic species, occurring throughout the Cenomanian.

Types and occurrence: Figured (fig. 9) and unfigured topotypes from the Greenhorn limestone (Hartland shale member), SE¼ sec. 31, T. 21 S., R. 22 W., in bank of creek about ¼ mile west of road, Hodgeman Co., Kansas. Collected by Max Furrer.

Unfigured hypotype from the Del Rio clay on Shoal Creek, just south of the 34th Street bridge, in Austin, Travis County, Texas. Collected by H. T. and A. R. Loeblich.

Figured and unfigured hypotypes from the Cenomanian, Lamont Geological Observatory submarine Core A 167–25, on the escarpment of the Blake Plateau, lat. 28°52′ N., long. 76°47′ W., from the following depths in a 175 cm. core length: 20–30 cm., 30–40 cm., 40–50 cm., 80–90 cm., and 170–175 cm. (fig. 8).

Figured (fig. 10) and unfigured hypotypes from the Grayson formation at Grayson Bluff on Denton Creek, 3½ miles northeast of Roanoke, Denton Co., Texas. Collected by H. T. and A. R. Loeblich, Sept., 1958.

Globigerinelloides eaglefordensis (Moreman)
Plate 2, figures 3–7

Anomalina eaglefordensis Moreman, 1927, Jour. Pal., vol. 1, no. 1, p. 99, pl. 16, fig. 9.
Planomalina caseyi Bolli, Loeblich and Tappan, 1957, U. S. Nat. Mus., Bull., no. 215, p. 24, pl. 1, fig. 4–5.
Not *Planulina eaglefordensis* (Moreman). – Cushman, 1940, Cushman Lab. Foram. Res., Contr., vol. 16, pt. 2, p. 32, pl. 6, figs. 4–5. – Cushman, 1946, U. S. Geol. Survey, Prof. Paper, no. 206, p. 156, pl. 64, figs. 8–9. – Frizzell, 1954, Texas Univ., Bur. Econ. Geol., Rept. Invest., no. 22, p. 132, pl. 21, fig. 13.

Test free, small, planispiral, partially evolute, biumbilicate, periphery rounded, peripheral outline lobulate, six to eight subglobular chambers in the final whorl, increasing gradually in size; sutures distinct, depressed, straight to gently curved, radial; wall calcareous, finely perforate, surface smooth to very finely hispid; aperture a low interiomarginal, equatorial arch with narrow bordering lip, the lateral portions of previous apertures and lips exposed as relict supplementary apertures in the umbilical region.

Greatest diameter of hypotype of fig. 6 is 0.25 mm., thickness is 0.10 mm. Other specimens range from 0.15 to 0.31 mm. in maximum diameter.

Remarks: Originally described as an *Anomalina*, the planktonic nature of this species had not been noted previously. Later references to this species, as *Planulina eaglefordensis* (Moreman) by Cushman and Frizzell were to a completely different species (probably *P. kansasensis* Morrow) which contained ten to twelve chambers per whorl (Cushman, 1946, p. 156), and had limbate sutures. Moreman described this species as having eight to nine chambers in the last whorl (his figured specimen showed seven and one-half) and depressed sutures. It is abundant in Cenomanian strata in many areas.

Planomalina caseyi Bolli, Loeblich and Tappan, 1957 was described from the Gault (Albian) of England, the generic assignment being on the basis of the characteristic relict apertures. It lacks the keeled periphery of *Planomalina*, however, and these noncarinate species are now referred to *Globigerinelloides*. Comparison of hundreds of specimens from many localities shows *P. caseyi* to be a synonym of *Globigerinelloides eaglefordensis* (Moreman).

Types and occurrence: Figured (figs. 5–6) and unfigured hypotypes from the Britton clay, Eagle Ford group, lower ten feet of the cut bank of a tributary to Mountain Creek, 3.6 miles west of Cedar Hills on the road to Mansfield, Dallas Co., Texas. Collected by H. T. and A. R. Loeblich, September 4, 1958.

Unfigured hypotypes from the Britton clay, Eagle Ford group, six to eleven feet above base of exposure, in north bank of Newton Branch, a short distance northeast of U. S. Highway 287, 3.3 miles west-northwest of junction with U. S. Highway 67 in Midlothian, Ellis Co., Texas. Collected by H. T. and A. R. Loeblich, September 5, 1958.

Unfigured hypotypes from the Britton clay, Eagle Ford group, basal five feet of dark gray, thin-bedded shale with thin limonitic concretionary layers in bank of Elm Fork of Trinity River, just east of California Crossing, 1.0 mile north of the University of Dallas campus, about ¼ mile west of Wildwood Road bridge over Elm Fork, west of Dallas, Dallas Co., Texas. Collected by H. T. and A. R. Loeblich, September 5, 1958.

Unfigured hypotypes from the basal Cenomanian, and from the *Inoceramus crippsi* and *Schloenbachia varians* zones of the Cenomanian, in Ziegelei Zeltberg at Luneburg, southeast of Hamburg, Niedersachsen, Germany.

Figured and unfigured hypotypes from the Cenomanian, Lamont Geological Observatory submarine core A 167–25, on the escarpment of the Blake Plateau, lat. 28°52'N., long. 76°47'W., from the following depths in a 175 cm. core length: 10 cm., 70–80 cm., 130–140 cm., 140–150 cm. (fig. 7) and 170–175 cm.

Figured hypotype (figure 3) and unfigured hypotypes from the Grayson formation at Grayson Bluff on Denton Creek, 3½ miles northeast of Roanoke, Denton County, Texas. Collected by H. T. and A. R. Loeblich, September, 1958.

Unfigured hypotypes from the Grayson formation on Village Creek, about 100 yards south of th Everman-Kennedale road bridge, two miles east of Everman, southeast of Fort Worth, Tarrant Co., Texas. Collected by H. T. and A. R. Loeblich.

Unfigured hypotypes from the Grayson formation, northwest facing slope, ¾ mile due east of Burleson, 0.2 mile northeast of the old Burleson-Alvarado road, Johnson Co., Texas. Collected by H. T. and A. R. Loeblich.

Figured (fig. 4) and unfigured hypotypes from the Del Rio clay on Shoal Creek, just south of the 34th Street bridge, in Austin, Travis Co., Texas. Collected by H. T. and A. R. Loeblich.

Genus **Planomalina** Loeblich and Tappan, 1946

Planomalina Loeblich and Tappan, 1946, Jour. Pal., vol. 20, no. 3, p. 257.

Type species: Planomalina apsidostroba Loeblich and Tappan, 1946 (= *P. buxtorfi* (Gandolfi), 1942). Fixed by original designation and monotypy.

Test free, planispiral, biumbilicate, involute to partially evolute, lobulate in outline; chambers angular-rhomboid; sutures radial, curved, elevated; wall calcareous, finely perforate, radial in structure, test ornamented by keel and thickened and nodose sutures; aperture an interiomarginal, equatorial arch, with the opening extending back at either side to the septum at the base of the chamber, the lateral umbilical portions of successive apertures remaining open as supplementary relict apertures, each with a remnant of the bordering apertural lip.

Remarks: With the typical keeled species of this genus, Bolli, Loeblich, and Tappan (1957) also included those species with rounded chambers, planispiral coiling, and relict apertures. *Biticinella* Sigal, 1956, was mentioned in a footnote (Bolli, Loeblich and Tappan, 1957, p. 23) as possibly synonymous with *Planomalina.* We now regard the present genus as containing only the keeled species; those without poreless margins or keels are placed in *Globigerinelloides* Cushman and ten Dam. *Biticinella* is regarded as a synonym of the last-named genus.

Planomalina buxtorfi (Gandolfi)
Plate 2, figures 1, 2

Planulina buxtorfi Gandolfi, 1942, Riv. Ital. Pal., vol. 48, no. 4, p. 103, pl. 3, fig. 7; pl. 5, figs. 3–6; pl. 6, figs. 1–3; pl. 8, fig. 8; pl. 9, fig. 2; pl. 12, fig. 2; pl. 13, figs. 13, 15; text-figs. 35 (1–11). – Cita, 1948, Riv. Ital. Pal. Strat., vol. 54, no. 2, p. 15, pl. 2, fig. 13. – Sigal, 1952, XIX Congr. Géol. Internat., ser. I, no. 26, p. 23, fig. 22.

Planomalina apsidostroba Loeblich and Tappan, 1946, Jour. Pal., vol. 20, no. 3, p. 258, pl. 37, figs. 22, 23. – Bermudez, 1952, Venezuela, Minist. Minas e Hidrocarb., Bol. Geol., vol. 2, no. 4, p. 92, pl. 16, figs. 4–6. – Frizzell, 1954, Texas, Univ., Bur. Econ. Geol., Rept. Invest. 22, p. 131, pl. 21, fig. 11. – Bolli, Loeblich and Tappan, 1957, U. S. Nat. Mus., Bull., no. 215, p. 23, pl. 1, figs. 2–3. – Bykova, Vasilenko, Voloshinova, Miatliuk and Subbotina, 1959, Osnovy Paleontologii, p. 287, text-figs. 595–596.

Planomalina? almadenensis Cushman and Todd, 1948, Cushman Lab. Foram. Res., Contr. vol. 24, p. 98, pl. 16, fig. 25.

Planomalina buxtorfi (Gandolfi). – Reichel, 1950, Eclogae Geol. Helv., vol. 42, no. 2, p. 616 (footnote). – Küpper, 1955, Cushman Found. Foram. Res., Contr., vol. 6, pt. 3, p. 117, pl. 18, fig. 8. – Bronnimann and Brown, 1956, Eclogae Geol. Helv., vol. 48, no. 2, text fig. 15. – Gandolfi, 1957, Cushman Found. Foram. Res., Contr., vol. 8, pt. 2, p. 64, pl. 8, fig. 6.

Planomalina cf. *P. apsidostroba* Loeblich and Tappan. – Bolli, 1959, Bull. Amer. Pal., vol. 39, no. 179, p. 259, pl. 20, fig. 1.

Test free, of small to medium size, planispiral, deeply biumbilicate, may be somewhat evolute so that part of earlier whorls is visible in the umbilical region, periphery keeled and peripheral outline lobulate; chambers increasing gradually in size as added, from eight to nine, or nearly ten chambers in the final whorl, about twice as broad as high; sutures distinct, strongly curved and limbate, early ones beaded to nodose; wall calcareous, perforate, surface smooth except for the thickened and beaded keel and sutures; aperture interiomarginal, equatorial, a relatively high and open arch, with a protruding lip, and situated at the base of a subtriangular apertural face, aperture extending laterally to the base of the chamber at each side, the lateral umbilical portions of successive apertures remaining open as supplementary relict apertures.

Diameter of holotype of *P. buxtorfi* is 0.41 mm.; the holotype of *P. apsidostroba* is 0.48 mm. and the holotype of *P. almadenensis* is 0.53 mm. in diameter. Other hypotypes range in diameter from 0.25 to 0.60 mm.

Remarks: Originally described from the upper Albian and lower Cenomanian of Switzerland as *Planulina*, the species has also been recorded from Italy, Algeria, and California. It was described as *Planomalina apsidostroba* from upper Albian strata of Texas, and was so recorded in Trinidad, but apparently does not range upward into the lower Cenomanian in these areas. The synonymy of *P. apsidostroba* with *P. buxtorfi* was first suggested by Reichel (1950). A comparison of the holotype of *P. almadenensis* Cushman and Todd with specimens of

P. buxtorfi shows them to be synonymous as well. *Planomalina almadenensis* was originally said to be larger than *P. apsidostroba* and was said to lack the peripheral keel and elevated sutures. However, the holotype shows a distinct and nodose keel, and the sutures are thickened. The slightly worn surface of the specimen probably accounts for the lack of elevation of the sutures. Although the holotype of *P. almadenensis* is somewhat larger than the typical forms of this species, the specimen is no larger than the extremes found elsewhere. *Planomalina almadenensis* is here regarded as a junior synonym of *P. buxtorfi*, as was suggested also by Küpper (1955, p. 117). Küpper regarded it as less evolute than *P. apsidostroba*, but only the gerontic specimens show a tendency to uncoil, and all three names are here regarded as equivalent, *P. buxtorfi* having priority.

In addition to the previously recorded occurrences, this species also has been found in subsurface strata of Cuba, and we have observed it in subsurface material from Pakistan.

Types and occurrence: Holotype of *Planomalina apsidostroba* Loeblich and Tappan (Cushman Coll. 45667) (pl. 2, fig. 1), from the Main Street formation (Albian), in a road cut on the south side of the Godley-Cleburne road, just uphill from the bridge across Nolan's River, 4.8 miles southeast of Godley, Johnson Co., Texas. Collected by H. T. and A. R. Loeblich, Jr.

Hypotype of figure 2 (USNM P5394) from the upper Paw Paw formation (Albian) 7½ feet below the contact with the overlying Main Street formation, on the south side of the road at the western edge of the Federal Narcotic Farm, southeast of Fort Worth, Tarrant Co., Texas. Collected by H. T. and A. R. Loeblich, Jr.

Unfigured hypotypes from the Cenomanian, core in Shell Oil Company's Punta Alegre well No. 1, Cuba. Holotype of *Planomalina? almadenensis* Cushman and Todd from the Cenomanian, road cut in SW¼ sec. 24, T. 8S., R. 1W., Mount Diablo Meridian, New Almaden district, Santa Clara Co., California.

Family **Schackoinidae** Pokorný, 1958

Schackoinidae Pokorný, 1958, Grundzüge Zool. Mikropal., vol. 1, p. 348.

Type genus: Schackoina Thalmann, 1932.

Previously included in the family Hantkeninidae, *Schackoina* was removed by Pokorný (1958, p. 348) and made the type genus for the family Schackoinidae, as it differed from the typical Hantkeninidae in being trochospiral in at least the early stages. A true relationship between *Schackoina* and *Hantkenina* is further suspect because of their different geologic ranges and the absence of intermediate forms in the intervening strata. Even the presence of the elongate "spines" in both genera is not a morphologic similarity, for those of *Schackoina* are hollow tubular elongations of the chambers, or tubulospines as defined by Gallitelli (1955). Banner and Blow (1959, p. 9) erroneously used the term "tubulospine" for the spines of the Hantkeninidae, and stated that the slender chamber extensions of *Schackoina* are "not true tubulospines, and have unthickened walls." Gallitelli (1955, p. 142) originally stated "The term 'tubulospine' is here proposed for spinelike extensions of the chambers, as found in *Schackoina* which are hollow and are connected internally with the chamber cavity and are not solid as are true spines." Hence, this term cannot be transferred to indicate the thick-walled spines of *Hantkenina.*

Banner and Blow (1959) also regarded the two genera *Schackoina* and *Hantkenina* as not closely related, but placed *Schackoina* in the subfamily Planomalininae of the family Hantkeninidae, including with it the genera *Leupoldina* Bolli, 1957, and *Pseudohastigerina* Banner and Blow, 1959, in addition to genera previously included by Bolli, Loeblich and Tappan, 1957 (i.e., *Planomalina, Globigerinelloides*, and *Hastigerinoides*).

As the subfamily Planomalininae was defined to include planispiral genera with relict apertures, the genus *Schackoina* does not seem to fit therein. In the many hundreds of free specimens of this genus in the writer's collection, none show the true relict openings found in *Planomalina* and *Hastigerinoides.* Furthermore, the presence of tubulospines also seems a valid basis for the separation of this genus from the Planomalinidae.

Schackoina and *Leupoldina* are thus here regarded as belonging to the Schackoinidae, a family restricted to the Cretaceous (Aptian to Maestrichtian). The genus *Pseudohastigerina* Banner and Blow, 1959, is not included in the Schackoinidae, as it has neither the trochospiral early coil nor the tubulospines of that family.

Genus Schackoina Thalmann, 1932

Schackoina cenomana (Schacko)
Plate 1, figures 2–7

Siderolina cenomana Schacko, 1897, Ver. Freunde Naturg. Mecklenburg, Archiv, vol. 50 (1896), p. 166, pl. 4, figs. 3–5. – Egger, 1900, K. Bayer. Akad. Wiss. München, Math.-Phys. Cl., Abh., vol. 21, no. 1 (1899), p. 174, pl. 21, fig. 42. – Franke, 1928, Preuss. Geol. Landesanst., Abh., N. F., vol. 111, p. 193, pl. 18, fig. 11a–c.

Hantkenina cenomana (Schacko). – Cushman and Wickenden, 1930, Cushman Lab. Foram. Res., Contr., vol. 6, p. 40, pl. 6, figs. 4–6.

Hantkenina (Schackoina) cenomana (Schacko). – Thalmann, 1932, Eclogae Geol. Helv., vol. 25, p. 288.

Schackoina gandolfii Reichel, 1947, Eclogae Geol. Helv., vol. 40, no. 2, p. 397, text-figs. 3a–g, 6 (3), 7 (3), 8a, 10 (1, 3, 4); pl. 8, fig. 1. – Aurouze and de Klasz, 1954, Soc. Géol. France, Bull., sér. 6, vol. 4, p. 99, text-fig. 1C. – Bolli, 1959, Bull. Amer. Pal., vol. 39, no. 179, p. 263, pl. 20, figs. 12–18.

Hastigerinoides rohri Bronnimann, 1952, Bull. Amer. Pal., vol. 34, no. 140, p. 55, text-fig. 29, pl. 1, figs. 8–9.
Schackoina cenomana (Schacko). – Noth, 1951, Austria, Geol. Bundesanst., Jahrb., Sonderband. 3, p. 74, pl. 5, figs. 9, 10. – Montanaro-Gallitelli, 1955, Micropaleontology, vol. 1, no. 2, pp. 143, 144. – Bolli, Loeblich and Tappan, 1957, U. S. Nat. Mus., Bull., no. 215, p. 26, pl. 2, figs. 1–2. – Bykova, Vasilenko, Voloshinova, Miatliuk and Subbotina, 1959, Osnovy Paleontologii, p. 300, text-fig. 676.
Schackoina sp. du groupe *cenomana* (Schacko). – Aurouze and de Klasz, 1954, Soc. Géol. France, Bull., sér. 6, vol. 4, pl. VI a.
Not *Schackoina* sp. cf. *S. gandolfii* Reichel. – Küpper, 1956, Cushman Found. Foram. Res., Contr., vol. 7, pt. 2, p. 44, pl. 8, fig. 4.

Test free, planispiral, tiny, consisting of about two whorls of subglobular chambers with three to four in the last whorl, enlarging rapidly in size and each produced into a long, hollow, centrally placed, peripheral tubulospine, commonly broken, but occasionally well preserved; sutures distinct, constricted; wall calcareous, finely perforate, surface smooth; aperture an interiomarginal equatorial arch, bordered above by a broad spatulate lip.

Hypotypes range from 0.13 to 0.20 mm. in diameter, exclusive of the tubulospines.

Remarks: Originally described from the Cenomanian of northern Germany, this species has only rarely been recorded under the original name. The Eagle Ford specimens are very similar to those from Germany. Similar forms have been considered juvenile specimens of *Schackoina multispinata* (Cushman and Wickenden) or *S. trituberculata* (Morrow). Various references have stated that *S. cenomana* lacks a tubulospine on the final chamber, but this is not true of most specimens, including those from Germany. This erroneous conclusion is based on the original figure of one such specimen by Schacko (1896), but other specimens have a tubulospine on every chamber. The number of chambers per whorl also varies from three to three and one-half or four, with three and one-half being the most frequent.

The specimens described from the Cenomanian of Switzerland by Reichel (1947), and by Aurouze and deKlasz (1954) as *Schackoina gandolfii*, appear identical in all respects to *S. cenomana*, as do those described as *Hastigerinoides rohri* Bronnimann, 1952, from the Gautier formation (Cenomanian) of Trinidad. The latter was regarded as a synonym of *S. gandolfii* by Bolli (1959), but we regard both *S. gandolfii* and *H. rohri* as junior synonyms of *S. cenomana*. This species is apparently of widespread occurrence in Cenomanian rocks, having been overlooked in some instances because of its small size. *Schackoina cenomana* was reported from the Calera limestone (Cenomanian) of California by Church (1952, p. 70). *Schackoina* cf. *S. gandolfii* of Küpper (1956, p. 44) from the "Antelope shale" of California, is not conspecific, nor even congeneric. Küpper noted that no spine attachments were present on early chambers and that only on the final chamber was the presence of a spine suggested by "a point of detachment where a spine was broken off." Examination of this figured specimen shows a break on the final chamber, but the specimen shows the elongated chambers characteristic of *Clavihedbergella simplex*, and the absence of spines on other chambers suggests that the break on the final chamber is wholly accidental, rather than an indication of the position of a spine. Küpper's specimen is therefore included in the synonymy of *C. simplex*.

Types and occurrence: Figured (figs. 5–7) and unfigured hypotypes from the Britton clay, Eagle Ford group, 32 to 37 feet above base of exposure in a cut bank of a tributary to Mountain Creek, 3.6 miles west of Cedar Hills on the road to Mansfield, Dallas Co., Texas. Collected by H. T. and A. R. Loeblich, September 4, 1958. Unfigured hypotypes also from the basal 10 feet of section, 10 to 15 feet above the base, and 20–25 feet above the base exposed at the above locality.

Unfigured hypotype from the Britton clay, Eagle Ford group, 10 to 15 feet above the base of the exposure, north bank of Newton Branch, a short distance northeast of U. S. Highway 287, 3.3 miles west-northwest of junction with U. S. Highway 67 in Midlothian, Ellis Co., Texas.

Figured hypotype (fig. 2) and unfigured hypotypes from the Greenhorn limestone (Hartland shale member), SE¼ sec. 31, T. 21 S., R. 22 W., north bank of creek about ¼ mile west of road, Hodgeman Co., Kansas. Collected by Max Furrer.

Unfigured hypotypes from the Greenhorn limestone (Hartland shale member) on county road ¼ mile north of Highway 156, 5.2 miles west-southwest of Gray, Hodgeman Co., Kansas. Collected by Max Furrer.

Unfigured hypotypes from the Cenomanian in small tributary to Clark Valley, 0.1 mile south of center of north line of sec. 8, T. 19 N., R. 5 W., Fruto Quadrangle, Glenn Co., California.

Figured hypotypes of figs. 3 and 4 (USNM P4644) from the *Schloenbachia varians* zone, and unfigured hypotypes from the *Inoceramus crippsi* zone at Ziegelei Zeltberg, at Luneburg, southeast of Hamburg, Niedersächsen, Germany.

Schackoina multispinata (Cushman and Wickenden)
Plate 1, figures 8–10

Hantkenina multispinata Cushman and Wickenden, 1930, Cushman Lab. Foram. Res., Contr., vol. 6, pt. 2, p. 40, pl. 6, figs. 4–6. – Cushman, 1931, Cushman Lab. Foram. Res., Contr., vol. 7, pt. 4, p. 88, pl. 11, figs. 10–11.
Schackoina multispinata (Cushman and Wickenden). – Cushman, 1933, Cushman Lab. Foram. Res., Spec. Publ., no. 5, pl. 35, figs. 9–10. – Cushman, 1946, U. S. Geol. Survey, Prof. Paper., no. 206, p. 148, pl. 61, figs. 11–12. –

AUROUZE AND DE KLASZ, 1954, Soc. Géol. France, Bull., sér. 6, vol. 4, p. 100, text-fig. 1D–G. – MONTANARO-GALLITELLI, 1955, Micropaleontology, vol. 1, no. 2, p. 144, table 1.

Hantkenina trituberculata MORROW, 1934, Jour. Pal., vol. 8, p. 195, pl. 29, figs. 24, 26–28.

Schackoina trituberculata (Morrow). – LOETTERLE, 1937, Nebraska, Geol. Survey, 2nd Ser., Bull. 12, p. 47, pl. 7, fig. 7. – CUSHMAN, 1946, U. S. Geol. Survey, Prof. Paper, no. 206, p. 148, pl. 61, figs. 13–16. – MONTANARO-GALLITELLI, 1955, Micropaleontology, vol. 1, no. 2, p. 142, pl. 1, fig. 11.

Schackoina cenomana (Schacko) subsp. *bicornis* REICHEL, 1947, Eclogae Geol. Helv., vol. 40, no. 2, p. 401, text-figs. 4a–g, 6 (4), 7 (4), 8b, 9, 10 (5, 6, 8, 9, 15). – AUROUZE AND DE KLASZ, 1954, Soc. Géol. France, Bull., sér. 6, vol. 4, p. 99, text-fig. 1B.

Schackoina moliniensis REICHEL, 1947, Eclogae Geol. Helv., vol. 40, no. 2, p. 402, text-figs. 5, 6 (5), 7 (5), 8c, 10 (12), 13; pl. 8, fig. 2.

Schackoina bicornis Reichel. – BYKOVA, VASILENKO, VOLOSHINOVA, MIATLIUK and SUBBOTINA, 1959, Osnovy Paleontologii, text-fig. 675.

Test free, small, in a low trochospiral coil; chambers few in number, increasing rapidly in size as added, subglobular to radial elongate, three or more rarely four in the final whorl, with an elongate radial tubulospine extending from the median portion of each chamber, the final one or two chambers commonly with two or three tubulospines per chamber, resulting in a very irregular test outline; sutures distinct, depressed, strongly constricted; wall calcareous, finely perforate, surface smooth to finely hispid, ornamented by the elongate tubulospines; aperture interiomarginal, equatorial, with a narrow bordering lip.

Greatest diameter of test, exclusive of tubulospines, ranges from 0.15 to 0.21 mm.

Remarks: Schackoina multispinata was described from the Cheval formation (Upper Cretaceous) of Manitoba, and has also been recorded from the Austin chalk and from the Pecan Gap chalk member of the Taylor marl in Texas. *Schackoina trituberculata* was first described from the Hartland shale member of the Greenhorn formation of Kansas and later recorded from the Niobrara formation of Kansas, Nebraska, and South Dakota, and the Upper Cretaceous (referred questionably to upper Senonian) of the northern Apennines, Italy. A comparison of the holotype of *S. trituberculata* (USNM no. 75373) and numerous topotypes with paratypes of *S. multispinata* (Cushman Coll. 13144) shows the two to be identical and *S. trituberculata* is thus a junior synonym. In addition to the above-mentioned occurrences, this species also occurs rarely in the Eagle Ford group of Texas.

The synonymy above shows that very little specific variation has been allowed in this group. *Schackoina bicornis* and *S. moliniensis* were both described from thin sections from bed 50, "Scaglia rossa", at Breggia. Examination of a large suite of free specimens from Kansas shows this species to be quite variable, and the "species" *bicornis* and *moliniensis* well within its limits. Reichel (1947, p. 404) also noted that *S. bicornis* and *S. moliniensis* are very close, and only distinguished by the presence of two or three double-spined chambers in *S. moliniensis*, instead of a single double-spined chamber in *S. bicornis*. The range chart given by Reichel (1947, fig. 11) shows that *S. moliniensis* occurred where the larger numbers of specimens of *Schackoina* were found (56 specimens were found in bed 50), suggesting that the larger number of double-spined chambers occurs in the adult specimens wherever the species is found in quantity, and is not a specific character. The number of spines visible in thin section may also depend on the position or plane of the thin section.

Schackoina cenomana bicornis Reichel of Küpper (1956) is slightly larger than usual for this species, and the figured specimen is somewhat crushed. However, it is otherwise similar to specimens from the Greenhorn and Eagle Ford, and the relatively large size is characteristic of many of the California specimens of the Cenomanian species.

Types and occurrence. – Figured (fig. 10) and unfigured hypotypes from the Greenhorn limestone (Hartland shale member), on county road, $\frac{1}{4}$ mile north of Highway 156, 5.2 miles west-southwest of Gray, Hodgeman Co., Kansas. Collected by Max Furrer.

Figured (fig. 9) and unfigured hypotypes from the Greenhorn limestone (Hartland shale member), SE$\frac{1}{4}$ sec. 31, T. 21 S., R. 22 W., north bank of creek, about $\frac{1}{4}$ mile west of road, Hodgeman Co., Kansas. Collected by Max Furrer.

Figured hypotype (fig. 8) from the Britton clay, Eagle Ford group, from 5 to 10 feet above base of exposure, north bank of Newton Branch, a short distance northeast of U. S. Highway 287, 3.3 miles west-northwest of junction with U. S. Highway 67 in Midlothian, Ellis Co., Texas. Collected by H. T. and A. R. Loeblich, Jr., September 5, 1958.

Schackoina primitiva Tappan
Plate 1, figure 1

Schackoina primitiva TAPPAN, 1940, Jour. Pal., vol. 14, no. 2, p. 123, pl. 18, fig. 14. – FRIZZELL, 1954, Texas, Univ., Bur. Econ. Geol., Rept. Invest. 22, p. 128, pl. 20, fig. 20. – MONTANARO-GALLITELLI, 1955, Micropaleontology, vol. 1, no. 2, p. 143, table 1.

Test free, small, biumbilicate, slightly trochospiral, chambers inflated centrally, three or four per whorl, increasing rapidly in size as added, with relatively short and blunt tubulospines, one arising from the center of each chamber at the periphery and of a length equal to one half the diameter of the test; sutures distinct, slightly depressed, very slightly constricted, so that periphery is not as distinctly lobulate as is usual for *Schackoina*; wall calcareous, surface smooth; aperture a low equatorial interiomarginal slit.

Greatest diameter of holotype (exclusive of tubulospines) 0.26 mm., least diameter 0.17 mm, length of tubulospine 0.10 mm., greatest thickness of test 0.10 mm.

Remarks: This extremely rare species is known only from the original types. It differs from *S. cenomana* in the entire, nonlobulate periphery, less rapid increase in chamber size and less inflated chambers.

Types and occurrence: Holotype (Cushman Coll. 25115) from about 35 feet below the exposed top of the Grayson formation (lower Cenomanian) at Grayson Bluff, on Denton Creek, 3½ miles northeast of Roanoke, Denton County, Texas. Collected by H. T. and A. R. Loeblich, Jr.

Family **Rotaliporidae** Sigal, 1958, emended

Rotaliporidae Sigal, 1958, Soc. Géol. France, C. R. Somm., no. 12, p. 264.

Rotaliporinae Sigal. – Banner and Blow, 1959, Palaeontology, vol. 2, pt. 1, p. 8.

Type genus: Rotalipora Brotzen, 1942

Coiling of test trochospiral, chambers angular to ovate or spherical; wall calcareous, perforate, radial in structure; primary aperture extraumbilical-umbilical, with relatively prominent bordering lip, may have secondary sutural apertures on the umbilical side, opening into the chambers at their posterior margin.

Range: Hauterivian to Maestrichtian.

This family was proposed to include *Ticinella*, *Biticinella*, *Rotalipora* and *Thalmanninella*, thus including both planispiral (*Biticinella*) and trochospiral genera. The secondary sutural apertures of *Ticinella* and *Rotalipora* are similar and distinct from the primary aperture; those of *Biticinella* we regard as lateral relict apertures, which are remnants of earlier primary apertures, relating these forms to the Planomalinidae. *Biticinella* itself is regarded as a synonym of *Globigerinelloides*.

Banner and Blow (1959, p. 8) included the Rotaliporinae (reduced to subfamily rank) in the family Hantkeninidae, regarding the apertural flaps of these trochospiral forms as portici, and analogous to the lateral apertural flanges of *Hantkenina*. We believe that the type of coiling is a character of family value, and thus consider this group as unrelated to either the Hantkeninidae or Planomalinidae (which were associated as subfamilies by Banner and Blow within the Hantkeninidae). Bolli, Loeblich and Tappan (1957) included with the Globorotaliidae the genera here placed in the Rotaliporidae, because of a similarity in appearance. The Globorotaliidae may develop secondary sutural apertures on the spiral side, but not on the umbilical side as in the Rotaliporidae.

The Rotaliporidae of Sigal is thus here largely included in the subfamily Rotaliporinae, and the similar genera which lack secondary sutural apertures are included in the subfamily Hedbergellinae, also placed in the family Rotaliporidae.

Subfamily **Hedbergellinae** Loeblich and Tappan, 1961

Hedbergellinae Loeblich and Tappan, 1961, Jour. Pal., vol. 35, no. 2, p. 309.

Type genus: Hedbergella Bronnimann and Brown, 1958

Coiling of test trochospiral, chambers spherical to ovate to subangular; wall calcareous, perforate, radical in structure; primary aperture extraumbilical-umbilical, with relatively prominent bordering lip, the lips of previous apertures commonly projecting into the umbilical region.

Range: Hauterivian to Maestrichtian.

This subfamily includes the genera *Hedbergella* Bronnimann and Brown, 1958, *Praeglobotruncana* Bermudez, 1952, and *Clavihedbergella* Banner and Blow, 1959. These genera include the most primitive of the planktonic forms, and in general are morphologically simple, undoubtedly having given rise at various stages in their phylogenetic development to the Rotaliporinae, Globotruncanidae, and possibly the Globorotaliidae and Globigerinidae. It is possible that the planispiral forms (Schackoinidae, Planomalinidae and Hantkeninidae) also arose from primitive Hedbergellinae.

Genera here included were placed with the Globorotaliidae by Bolli, Loeblich and Tappan, 1957, in the Globorotaliidae and Rotaliporidae by Sigal 1958, and in the Rotaliporinae, family Hantkeninidae by Banner and Blow, 1959.

Genus **Hedbergella** Bronnimann and Brown, 1958

Hedbergella Bronnimann and Brown, 1958, Washington Acad. Sci., Jour., vol. 48, no. 1, p. 16.

Type species: Anomalina lorneiana d'Orbigny var. *trocoidea* Gandolfi, 1942. Fixed by original designation.

Test free, trochospiral, biconvex, umbilicate, periphery rounded, with no indication of keel or poreless margin; chambers globular to ovate; sutures depressed, radial, straight to curved; wall calcareous, finely perforate, radial in structure, surface smooth to hispid or rugose; aperture an interiomarginal, extraumbilical-umbilical arch commonly bordered above by a narrow lip or spatulate flap, and in forms with broad open umbilicus successive apertural flaps may remain visible to present a serrate or scalloped border around the umbilicus.

Remarks: Hedbergella includes species which are otherwise similar to *Praeglobotruncana*, but lack a keel or poreless margin. The rounded chambers are reminiscent of *Globigerina*, but the aperture is extraumbilical, rather than umbilical, and the umbilicus is commonly narrow. Banner and Blow (1959, p. 8) regard *Hedbergella* as a subgenus of *Praeglobotruncana*, but we consider them sufficiently distinct to have generic status, and believe the taxonomy to be less cumbersome without utilization of subgeneric names.

Hedbergella amabilis Loeblich and Tappan, **new species**
Plate 3, figures 1–10

Globigerina cretacea d'Orbigny. – MOREMAN, 1927, Jour. Pal., vol. 1, no. 1, p. 100, pl. 16, figs. 14–15.

Test free, of medium size, in a nearly flat trochospiral coil of 2 to 2½ whorls; five or more rarely six subglobular chambers in the final whorl, increasing rapidly in size as added, umbilicus broad and open; sutures deeply constricted, distinct; wall calcareous, distinctly but very finely spinose; aperture a low interiomarginal, extraumbilical arch, the broad spatulate lip commonly with a somewhat irregular margin.

Greatest diameter of holotype 0.42 mm., thickness 0.19 mm. Paratypes range from 0.24 to 0.45 mm. in diameter.

Remarks: This species is larger than *Clavihedbergella simplex* (Morrow), with a more finely spinose surface, and lacks the radial elongation of the chambers characteristic of that species. It differs from *Hedbergella brittonensis*, new species, in the nearly flat spire, finely spinose surface and the broad spatulate apertural lip. *Hedbergella planispira* (Tappan) and *H. trocoidea* (Gandolfi) have more chambers per whorl, and less constricted sutures; *H. planispira* is much smaller in size and *H. trocoidea* is relatively thicker. *Hedbergella delrioensis* (Carsey) is larger, much thicker, higher spired, and more coarsely spinose.

The specific name is from the Latin, *amabilis*, meaning lovely.

Types and occurrence: Holotype (fig. 1), figured (fig. 4) and unfigured paratypes from the Britton clay, Eagle Ford group, 45 to 50 feet above base of exposure, figured paratypes (figs. 2, 3, 5) and unfigured paratypes from 27 to 33 feet above base, and unfigured paratypes from 10 to 15 feet above base of exposure, in cut bank of tributary to Mountain Creek, 3.6 miles west of Cedar Hills, on road to Mansfield, Dallas County, Texas. Collected by H. T. and A. R. Loeblich, September 4 1958.

Figured paratype (fig. 9) and unfigured paratypes from the Britton clay, Eagle Ford group, from 15 to 20 feet above the base of the exposure, and (fig. 10) from 5 to 10 feet above the base of the exposure, in the north bank of Newton Branch, northeast of U. S. Highway 287, 3.3 miles west-northwest of the junction with U. S. Highway 67, in Midlothian, Ellis County, Texas. Collected by H. T. and A. R. Loeblich, September 5, 1958.

Figured (figs. 7, 8) and unfigured paratypes from the Atkinson formation, Humble Oil and Refining Company, Bennett and Langsdale No. 1, in core from 3,700 to 3,710 feet, Echols Co., Georgia.

Figured (fig. 6) paratype from a 175 cm. core of Cenomanian age, Lamont Geological Observatory submarine core A-167-25, on escarpment of the Blake Plateau, lat. 28°52′ N., long. 76°47′ W., north of the Bahama Islands, at a depth of 40–50 cm.

Hedbergella brittonensis Loeblich and Tappan, **new species**
Plate 4, figures 1–8

Globigerina cretacea d'Orbigny. – MORROW, 1934, Jour. Pal., vol. 8, no. 2, p. 198, pl. 30, figs. 7–8, 10a–b.

Globigerina cf. *G. cretacea* d'Orbigny. – APPLIN, 1955, U. S. Geol. Survey, Prof. Paper, no. 264–I, p. 196, pl. 48, figs. 23–24.

Globigerina sp., KÜPPER, 1955, Cushman Found. Foram. Res., Contr., vol. 6, pt. 3, p. 117, pl. 18, fig. 9a–c.

Test free, in a medium to high trochispiral coil of two and one-half to three volutions, all visible on the elevated spiral side, only the five to six or rarely seven chambers of the final whorl visible around the deep and broad umbilicus of the opposite side; chambers increasing gradually in size; sutures distinct, deeply constricted, radial to gently curved; wall calcareous, distinctly perforate, surface prominently spinose; aperture an arch opening into the umbilicus and bordered by a distinct lip, with the lips of earlier chambers occasionally preserved around the umbilicus.

Greatest diameter of holotype 0.37 mm., thickness 0.33 mm. Paratypes range from 0.34 to 0.49 mm. in diameter.

Remarks: This species is characterized by the high spire and distinctly spinose surface. It resembles *Globigerina paradubia* Sigal in general size and appearance, but apertural, umbilical and surface characters of the latter have not been described, hence it is impossible to be certain of the specific characters. The present species also has fewer chambers per whorl than does the figured specimen of *G. paradubia. Globigerina kelleri* Subbotina differs in having depressed chambers, less incised sutures, and a flattened umbilical side.

Examination of the specimen figured as *Globigerina* sp. by Küpper (1955) shows it to belong to the present species.

Types and occurrence: Holotype (fig. 1), figured paratypes (figs. 5–7) and unfigured paratypes from the Britton clay (Eagle Ford group), 43 to 48 feet above base, and figured paratype (fig. 4) from 10 to 15 feet above the base of the cut bank of tributary to Mountain Creek, 3.6 miles west of Cedar Hills on road to Mansfield, Dallas Co., Texas. Collected by H. T. and A. R. Loeblich.

Figured (figs. 2, 3) and unfigured paratypes from the Greenhorn limestone (Hartland shale member), SE¼ sec. 31, T. 21 S., R. 22 W., north bank of creek about ¼ mile west of road, Hodgeman Co., Kansas. Collected by Max Furrer.

Unfigured paratypes from the Atkinson formation, Sun Oil Co., Barlow No. 1, in cores from 3709 to 3729 feet, Clinch Co., Georgia.

Figured paratype (fig. 8) from core at 3700–3710 feet, and unfigured paratypes from cores from 3670 to 3690 feet, all from the Atkinson formation, Humble Oil and Refining Company, Bennett and Langsdale No. 1, Echols Co., Georgia.

Hedbergella delrioensis (Carsey)
Plate 2, figures 11–13

Globigerina cretacea d'Orbigny var. *del rioensis* CARSEY, 1926, Texas, Univ., Bull., no. 2612, p. 43.
Globigerina cretacea d'Orbigny. – TAPPAN, 1940, Jour. Pal., vol. 14, no. 2, p. 121, pl. 19, fig. 11. – TAPPAN, 1943, Jour. Pal., vol. 17, no. 5, p. 512, pl. 82, figs. 16–17.
Globigerina gautierensis BRONNIMANN, 1952, Bull. Amer. Pal., vol. 34, no. 140, p. 11, pl. 1, figs. 1–3, text-fig. 2.
Globigerina delrioensis Carsey. – FRIZZELL, 1954, Texas, Univ., Bur. Econ. Geol., Rept. Invest. 22, p. 127, pl. 20, fig. 1.
Praeglobotruncana gautierensis (Bronnimann). – BOLLI, 1959, Bull. Amer. Pal., vol. 39, no. 179, p. 265, pl. 21, figs. 3–6.
Praeglobotruncana (Hedbergella) delrioensis (Carsey). – BANNER AND BLOW, 1959, Palaeontology, vol. 2, pt. 1, p. 8.

Test free, in a low trochospiral coil of about two volutions, early whorl flush to slightly depressed below the final whorl on the spiral side, opposite side deeply umbilicate, peripheral outline strongly lobulate; chambers much inflated, nearly spherical, increasing rapidly in size as added, with four to six chambers in the final whorl, most commonly five; sutures distinct, straight to slightly curved, deeply constricted; wall calcareous, distinctly perforate, earlier chambers with a papillate surface, final chamber less ornamented, no indication of a keel or poreless margin; aperture an arch on the umbilical side, interiomarginal and extraumbilical-umbilical, partially covered by a relatively large spatulate lip which flares slightly at its umbilical end.

Hypotypes range from 0.23 to 0.57 mm. in diameter. Figured topotypes are 0.33 and 0.41 mm. in diameter.

Remarks: Although originally regarded by Carsey as a variety of *Globigerina cretacea*, the species was generally placed within *G. cretacea* until elevated to specific rank by Frizzell, 1954. As earlier publications did not completely describe the surface and other characters of this species, Bronnimann, 1952, described it from Trinidad as a new species, *G. gautierensis*. This latter name is thus a junior synonym of *Globigerina delrioensis* Carsey.

In recent emendations of the genus, *Globigerina* has been restricted to include only those forms that are like the type species, with globular chambers and umbilical aperture. The aperture of the present species is extraumbilical. It cannot be placed in *Praeglobotruncana* because of the lack of any trace of keel or poreless margin, and thus fits the generic diagnosis of *Hedbergella* Bronnimann and Brown in having a rough wall, trochospiral coil, globular chambers, rounded interiomarginal aperture, and short apertural flaps. It was referred to *Hedbergella* by Banner and Blow (1959, p. 8). The chambers extend into the umbilicus with no trace of umbilical tegilla (as in *Rugoglobigerina*), and without secondary sutural apertures (as in *Rotalipora* and *Ticinella*). Although similar in general appearance to *Globigerina infracretacea* Glaessner, 1937, the present species is about twice as large. A study of type material of *G. infracretacea* would be necessary to determine whether or not it should be included as a junior synonym of *Hedbergella delrioensis*.

Types and occurrence: Figured (figs. 11, 12) and unfigured topotypes from the Del Rio clay, on Shoal Creek just south of the 34th Street bridge, in Austin, Travis Co., Texas. Collected by H. T. and A. R. Loeblich.

Unfigured hypotypes from the Del Rio clay, in small branch just south of the Belton-Temple highway, 1.4 miles east-northeast of the easternmost of two railroad underpasses of the St. Louis and Santa Fe Railroad, Bell Co., Texas. Collected by H. T. and A. R. Loeblich.

Figured (fig. 13) and unfigured hypotypes from the Grayson formation at Grayson Bluff on Denton Creek, 3½ miles northeast of Roanoke, Denton Co., Texas. Collected by H. T. and A. R. Loeblich.

Unfigured hypotypes from the Cenomanian, Lamont Geological Observatory submarine core A 167–25, on escarpment of Blake Plateau, lat. 28°52′ N., long. 76°47′ W., depth in core 30–40 cm.

Hedbergella hiltermanni Loeblich and Tappan, new species
Plate 4, figures 12–13

Test free, in a relatively high trochospiral coil of about three volutions; chambers globular and inflated, increasing gradually in size as added, all chambers visible on the spiral side, only the five or six, or rarely four, chambers of the final whorl visible on the opposite side around the deep and narrow umbilicus; sutures distinct, depressed, radial and strongly constricted; wall calcareous, perforate, surface cancellate to rugose; aperture a low umbilical arch.

Greatest diameter of holotype 0.49 mm., thickness 0.44 mm. Paratypes range from 0.36 to 0.52 mm. in diameter.

Remarks: This species resembles *Hedbergella washitensis* (Carsey) in the extremely ornate surface, but the surface tends to develop elongate ridges in addition to the polygonal honeycomb pattern. The cancellation is also much coarser than in *H. washitensis*. The spire is more elevated, there are commonly more chambers per whorl, and a less rapid increase in chamber size than in *H. washitensis*.

The surface ornamentation is somewhat suggestive of *Rugoglobigerina rugosa* (Plummer), but there are no umbilical tegilla and no accessory apertures in the present species.

Hedbergella brittonensis, new species, differs from the present species in having a lower spire, less ornamented surface, wider umbilicus, and an extraumbilical-umbilical aperture.

This species is named in honor of Dr. Heinrich Hiltermann, of Hannover, Germany, in recognition of his work on Cretaceous microfaunas, and for his assistance in obtaining the material from which this species is described.

Types and occurrence: Holotype (fig. 12) and figured and unfigured paratypes from the basal Cenomanian in Ziegelei Zeltberg at Luneberg, southeast of Hamburg, Niedersächsen, Germany.

Hedbergella planispira (Tappan)

Plate 5, figures 4–11

Globigerina planispira TAPPAN, 1940, Jour. Pal., vol. 14, no. 2, p. 122, pl. 19, fig. 12. – TAPPAN, 1943, Jour. Pal., vol. 17, no. 5, p. 513, pl. 83, fig. 3. – LOZO, 1944, Amer. Midland Nat., vol. 31, no. 3, p. 562, pl. 3, fig. 5. – FRIZZELL, 1954, Texas, Univ., Bur. Econ. Geol., Rept. Invest. 22, p. 127, pl. 20, fig. 2.

Globigerina globigerinelloides SUBBOTINA, 1949, Microfauna Oilfields USSR, vol. 2, p. 32, pl. 2, figs. 11–16. – SUBBOTINA, 1953, Trudy Vses. Neft. Naukno-Issledov. Geol.-Razved. Inst., n. ser., vol. 76, p. 51, pl. 1, figs. 11–12.

Globorotalia? youngi FOX, 1954, U. S. Geol. Survey, Prof. Paper, no. 254–E, p. 119, pl. 26, figs. 15–18.

Praeglobotruncana planispira (Tappan). – BOLLI, LOEBLICH AND TAPPAN, 1957, U. S. Nat. Mus., Bull., no. 215, p. 40, pl. 9, fig. 3. – BOLLI, 1959, Bull. Amer. Pal., vol. 39, no. 179, p. 267, pl. 22, figs. 3–4.

Praeglobotruncana modesta BOLLI, 1959, Bull. Amer. Pal., vol. 39, no. 179, p. 267, pl. 22, fig. 2.

Test free, tiny, spiral side with a low trochospiral coil of two to two and one-half whorls, opposite side deeply umbilicate; five to seven chambers (commonly six or seven) in the final whorl, chambers globular, increasing regularly in size as added; sutures distinct, slightly depressed, radial to gently curved; wall calcareous, finely perforate, surface finely hispid, but some specimens apparently worn smooth before preservation; aperture interiomarginal, extraumbilical-umbilical, with a narrow bordering lip which expands as a subtriangular flap near the umbilicus, the flaps of preceding chambers remaining visible around the umbilical depression.

Holotype is 0.24 mm. in maximum diameter, 0.11 mm. in thickness through center. Other specimens range from 0.11 to 0.26 mm. in diameter.

Remarks: Originally described as having a smooth surface, the species is nevertheless finely hispid. The most distinctive characters are the nearly flat spiral side, and the gradually enlarging subglobular chambers. Small specimens have a flatter appearance than do the adult specimens, as commonly the later chambers are somewhat more inflated. This has led to the erection of two species in some regions, such as in Trinidad, where *Praeglobotruncana modesta* is almost identical with *P. planispira*, except for being slightly smaller. In all areas observed, there is a similar variation in size, and we regard them as merely intraspecific gradation.

The generic assignment of this form has varied considerably, in addition to the many specific names proposed. For the first decade after the original description, all references to this form placed it in *Globigerina*, because of the globular chambers. With the increase in economic and stratigraphic importance of the planktonic forms, various generic revisions were made and the name *Globigerina* was usually reserved for those forms, like the type species, with a large umbilical aperture. Species formerly placed in *Globigerina* were then variously placed in *Globorotalia*, *Praeglobotruncana*, or other genera, on the basis of their respective apertural characters.

The writers have previously regarded this species as *Praeglobotruncana*, because of the extraumbilical-umbilical aperture (Bolli, Loeblich and Tappan, 1957), at that time considering *Hedbergina* Bronnimann and Brown, 1956, invalid on the basis of its type species. *Hedbergella* Bronnimann and Brown, 1958, differs from *Praeglobotruncana* in lacking any trace of a keel, but has a similar aperture. The present species seem to fit well into the genus *Hedbergella*.

Superficially, small specimens of *Globigerinelloides bentonensis* (Morrow), *Praeglobotruncana delrioensis* (Plummer), or *Hedbergella delrioensis* (Carsey) are similar to the present species, but *G. bentonensis* is completely planispiral, with the spire equally depressed on both sides, and juvenile specimens of the other species show more rapid increase in chamber size and fewer chambers in the final whorl. It differs from the somewhat similar *H. infracretacea* (Glaessner) in having more chambers per whorl, a more gradual increase in chamber size and less inflated chambers.

Globigerina gaultina Morozova, 1948, is a Russian form closely resembling this species, but was placed in *Ticinella* by Subbotina (1953, p. 165), and therefore is probably distinct, as *Ticinella* is characterized by secondary sutural apertures.

Described from the Greenhorn limestone as *Globorotalia? youngi* Fox, the species was stated to resemble closely *Globorotalia? multiloculata* Morrow. The latter species has the distinct secondary sutural apertures on the umbilical side characteristic of *Ticinella*, whereas the present species has only a primary aperture.

Praeglobotruncana modesta Bolli was described from the Gautier formation of Trinidad (*Rotalipora appenninica appenninica* zone, of Cenomanian age), and appears to be identical with this species. It occurs with the same planktonic assemblage in Trinidad as it does in the Cenomanian of Texas.

The species occurs in the upper Albian and Cenomanian Washita and Eagle Ford groups of Texas, in the Greenhorn limestone of South Dakota, Wyoming and Kansas, in a submarine core from the Blake Plateau, in the Cenomanian of Germany, the Albian and Cenomanian of the U.S.S.R., and Trinidad.

Types and occurrence: Figured (figs. 7, 8) and unfigured topotypes from the Grayson formation at Grayson Bluff on Denton Creek, 3½ miles northeast of Roanoke, Denton Co., Texas. Collected by H. T. and A. R. Loeblich.

Unfigured hypotypes from the Del Rio clay, on Shoal Creek, just south of the 34th Street bridge in Austin, Travis Co., Texas. Collected by H. T. and A. R. Loeblich.

Figured (figs. 4–6, 9, 10) and unfigured hypotypes from the Britton clay (Eagle Ford group), 42 feet above the base of cut bank of a tributary to Mountain Creek, 3.6 miles west of Cedar Hills on road to Mansfield, Dallas Co., Texas. Collected by H. T. and A. R. Loeblich.

Unfigured hypotypes from the Greenhorn limestone (Hartland shale member), SE¼ sec. 31, T. 21 S., R. 22 W., north bank of creek, about ¼ mile west of road, Hodgeman Co., Kansas. Collected by Max Furrer.

Unfigured hypotypes from the Cenomanian *Inoceramus crippsi* and *Schloenbachia varians* zones in Ziegelei Zeltberg at Luneburg, Province Niedersächsen, Germany.

Figured (fig. 11) and unfigured hypotypes from a 175 cm. core of Cenomanian age, Lamont Geological Observatory submarine core A 167–25, on escarpment of the Blake Plateau, lat. 28°52′ N., long. 76°47′ W., north of the Bahama Islands.

Hedbergella portsdownensis (Williams-Mitchell)
Plate 5, figure 3

Globigerina portsdownensis WILLIAMS-MITCHELL, 1948, Geol. Assoc., Proc., vol. 59, pt. 2, p. 96, pl. 8, fig. 4.

Test free, low trochospiral; all chambers of the two to three whorls visible on the spiral side, only the five to six chambers of the final whorl visible on the broadly umbilicate opposite side, chambers globular, spire low, peripheral outline lobulate, periphery broadly rounded; sutures distinct, deeply constricted, radial; wall calcareous, finely perforate, surface finely cancellate; aperture a high interiomarginal arch, extending from the umbilicus to the peripheral margin and bordered by a narrow lip which may be broken away.

Greatest diameter of figured hypotype 0.36 mm., thickness 0.24 mm. Other hypotypes range from 0.29 to 0.39 mm. in maximum diameter.

Remarks: The present species is here placed in the genus *Hedbergella* Bronnimann and Brown, as it has an extraumbilical rather than umbilical aperture. The lack of a poreless margin or keel separates it from species of the genus *Praeglobotruncana.*

Hedbergella portsdownensis differs from *H. planispira* (Tappan) in having more inflated and globular chambers and more deeply constricted sutures, and in being two to three times as large. *Hedbergella delrioensis* (Carsey) differs in lacking the much elevated spire of the present species.

Types and occurrence: Figured and unfigured hypotypes from the Cenomanian, *Inoceramus crippsi* zone in Ziegelei Zeltberg at Luneburg, southeast of Hamburg, Niedersächsen, Germany.

Hedbergella trocoidea (Gandolfi)
Plate 5, figures 1–2

Anomalina lorneiana d'Orbigny var. *trocoidea* GANDOLFI, 1942, Riv. Ital. Pal., vol. 48, no. 4, p. 98, pl. 2, fig. 1; pl. 4, figs. 2–3; pl. 13, figs. 2, 5. – NOTH, 1951, Austria, Geol. Bundesanst., Jahrb., Sonderband 3, p. 80, pl. 4, figs. 27–28.

Anomalina lorneiana d'Orbigny. – GANDOLFI, 1942, Riv. Ital. Pal., vol. 48, mem. 4, p. 98, pl. 4, figs. 1, 19; pl. 8, fig. 2; pl. 13, figs. 1, 4.

Globigerina almadenensis CUSHMAN AND TODD, 1948, Cushman Lab. Foram. Res., Contr. vol. 24, pt. 4, p. 95, pl. 16, figs. 18–19.

Hedbergina seminolensis (Harlton). – BRONNIMANN AND BROWN, 1956, Eclogae Geol. Helv., vol. 48, no. 2, p. 529, pl. 20, figs. 4–6.

Hedbergella trocoidea (Gandolfi). – BRONNIMANN AND BROWN, 1958, Washington Acad. Sci., Jour., vol. 48, no. 1, p. 16, fig. 1.

Praeglobotruncana (Hedbergella) trocoidea (Gandolfi). – BANNER AND BLOW, 1959, Palaeontology, vol. 2, pt. 1, p. 18.

Test free, of medium size, low trochospiral coil of about two volutions, early whorls not elevated above later chambers on spiral side, opposite side with deep and narrow umbilicus, periphery broadly rounded, peripheral outline lobulate; chambers numerous, inflated and nearly globular, increasing gradually in size as added, six or seven in the final whorl; sutures distinct, depressed, radial and straight; wall calcareous, distinctly perforate, surface of early chambers may be spinose, that of final chambers smooth, no keel or indication of a poreless margin; aperture a low, interiomarginal, extraumbilical-umbilical arch.

Greatest diameter of hypotype of fig. 2, 0.39 mm., greatest thickness 0.18 mm.; other hypotypes range from 0.26 to 0.39 mm. in diameter.

Remarks: This species was originally placed in *Anomalina*, which it resembles in the nearly planispiral coil, and relatively coarse perforations. It differs in both wall structure and apertural character, however, and in 1958 was made the type species of the genus *Hedbergella* Bronnimann and Brown. Described from the "Scaglia

variegata" (Aptian or Albian) of Switzerland, this species was later also recorded from Austria and Cuba. It is here recorded from the Cenomanian of the Blake Plateau, taken in a submarine core.

Globigerina almadenensis Cushman and Todd, from the Cenomanian of California, is identical with the present form. It had been placed in the synonymy of *Globotruncana* (*Rotundina*) *stephani stephani* by Küpper (1955, p. 116), but differs from that species in having globular chambers, in having an extremely rugose surface, and in lacking a keel.

Hedbergella trocoidea differs from *H. planispira* (Tappan) in being much larger, about three times as large, and in having a somewhat greater increase in chamber size, and a more rugose or spinose surface.

Types and occurrence: Figured (fig. 2) and unfigured hypotypes from the Cenomanian, Lamont Geological Observatory submarine Core A 167–25, on escarpment of Blake Plateau, lat. 28°52′ N., long. 76°47′ W., depth in core 10 cm. Unfigured hypotypes from 70 to 80 cm. and figured (fig. 1) und unfigured hypotypes from 140 to 150 cm. in the above core.

Hedbergella washitensis (Carsey)
Plate 4, figures 9–11

Globigerina washitensis Carsey, 1926, Texas, Univ., Bull., no. 2612, p. 44, pl. 7, fig. 10, pl. 8, fig. 2. – Plummer, 1931, Texas, Univ., Bull., no. 3101, p. 193, pl. 13, fig. 12. – Tappan, 1940, Jour. Pal., vol. 14, no. 2, p. 122, pl. 19, fig. 13. – Tappan, 1943, Jour. Pal., vol. 17, no. 5, p. 513, pl. 83, figs. 1–2. – Lozo, 1944, Amer. Midland Nat., vol. 31, no. 3, p. 563, pl. 3, fig. 4. – Loeblich and Tappan, 1949, Jour. Pal., vol. 23, no. 3, p. 265, pl. 51, fig. 4. – Frizzell, 1954, Texas, Univ., Bur. Econ. Geol., Rept. Invest. 22, p. 127, pl. 20, fig. 9. – Bolin, 1956, Jour. Pal., vol. 30, no. 2, p. 293, pl. 39, figs. 2–3, text-fig. 5 (11a–b). – Bolli, 1959, Bull. Amer. Pal., vol. 39, no. 179, p. 271, pl. 23, figs. 6–7.

Test free, relatively large, with low trochospiral coil of about two volutions, spiral side convex, opposite side deeply umbilicate; chambers inflated and globular, increasing rapidly in size as added, from three and one-half to six, but most commonly four, chambers in the final whorl; sutures of final whorl distinctly depressed, radial, resulting in a lobulate peripheral outline, the sutures of the earlier whorl largely obscured by the coarse surface ornamentation; wall calcareous, finely perforate, surface with coarse reticulations giving a honeycomb appearance, the much elevated ridges leaving deep polygonal pits between them; aperture nearly umbilical in position and consisting of a high interiomarginal arch.

Hypotypes range from 0.16 to 0.54 mm. in diameter. Figured topotype is 0.53 mm. in diameter and 0.34 mm. in thickness.

Remarks: The very distinctive ornamentation of this species permits its easy recognition. The occasionally almost umbilical aperture is characteristic of *Globigerina* s. s., unlike the majority of Cretaceous species previously so referred, but all gradations are found to the characteristic umbilical-extraumbilical aperture characteristic of *Hedbergella*.

Hedbergella washitensis has been reported from the Albian and Cenomanian strata of Texas and Oklahoma, and equivalent strata in Minnesota, in Trinidad, and in Algeria. Bolin (1956) regarded the Minnesota strata in which the species was found as Cenomanian in age and considered that the Minnesota occurrence extended the geologic range as well as the geographic range. The species was originally described from the Del Rio clay of central Texas, which is included in the Washita group, Comanche series, which is generally placed in the Lower Cretaceous, although it is nevertheless of Cenomanian age. Its geographic occurrence is also herein extended to include the submarine Blake Plateau, north of the Bahama Islands.

Types and occurrence: Figured (fig. 11) and unfigured topotypes from the Del Rio clay, on west bank of Shoal Creek just south of the 34th Street bridge in Austin, Travis Co., Texas. Collected by H. T. and A. R. Loeblich.

Unfigured hypotypes from the Del Rio clay, southwest corner sec. 39, block G 12, about 4 miles west of Terlingua, Brewster Co., Texas.

Unfigured hypotypes from the Grayson formation, Grayson Bluff, on Denton Creek, 3½ miles northeast of Roanoke, Denton Co., Texas. Collected by H. T. and A. R. Loeblich.

Figured and unfigured hypotypes from the Cenomanian, Lamont Geological Observatory submarine core A 167–25, on escarpment of Blake Plateau, lat. 28°52′ N., long. 76°47′ W., in a 175 cm. core at depths of 30–40 cm. (fig. 9), 40–50, 50–60, 70–80, 140–150 cm. (fig. 10) and 150–160 cm.

Genus **Clavihedbergella** Banner and Blow, 1959

Praeglobotruncana (Clavihedbergella) Banner and Blow, 1959, Palaeontology, vol. 2, pt. 1, p. 8, 18.

Type species: Hastigerinella subcretacea Tappan, 1943. Fixed by original designation.

Test free, low trochospiral, biconvex, broadly umbilicate, peripheral margin rounded, peripheral outline deeply lobulate, no keel or poreless margin; early chambers globular to ovate, later ones clavate to radial-elongate; sutures strongly constricted, radial, straight to curved; wall calcareous, finely perforate, radial in structure, surface smooth to hispid; aperture an interiomarginal, extraumbilical-umbilical arch, with a narrow bordering lip or spatulate flap (porticus).

Remarks: The species placed in this genus by Banner and Blow were originally described as *Hastigerinella* and *Hastigerinoides*, and were included in *Praeglobotruncana* by Bolli, Loeblich and Tappan (1957). *Clavihedbergella* was described in 1959 as a subgenus of *Praeglobotruncana* differing from *Praeglobotruncana* s. s. in lacking an imperforate margin and in having radial-elongate chambers. It differs from *Hedbergella* in having radial-elongate chambers, and from *Hastigerinella* in having the apertural flaps or portici.

Although *Clavihedbergella* was described as ranging from upper Albian to Turonian, thus being more restricted than *Hedbergella* (Banner and Blow, 1959, p. 17), we also have excellent examples of *Clavihedbergella* in Aptian strata of both hemispheres.

Clavihedbergella moremani (Cushman)
Plate 5, figures 12–16

Hastigerinella moremani Cushman, 1931 (part), Cushman Lab. Foram. Res., Contr., vol. 7, p. 86, pl. 11, fig. 1 (not figs. 2–3). – 1946 (part), U. S. Geol. Survey, Prof. Paper, no. 206, p. 147, pl. 61, fig. 1 (not figs. 2–3). – Frizzell, 1954 (part), Texas, Univ., Bur. Econ. Geol., Rept. Invest. 22, p. 127, pl. 20, fig. 11 (not fig. 12).

Test free, low trochospiral; early portion with globular chambers, about four to five per whorl, later chambers becoming elongated, ovate to cylindrical and finally clavate, with bulbous terminal portion, as many as six chambers in the final whorl in well-developed specimens; sutures distinct, depressed, radial, later ones deeply constricted; wall calcareous, finely perforate, with numerous blunt spine bases, probably remnants of elongate spines; aperture an interiomarginal arch, umbilical to peripheral, bordered with a narrow lip.

Hypotype of figure 14 is 0.43 mm. in maximum diameter; hypotype of figure 15 is 0.50 mm. in maximum diameter. Other hypotypes range from 0.20 to 0.50 mm. in maximum diameter.

Remarks: Paratypes referred to this species by Cushman (1931, pl. 11, figs. 2–3) are of a more robust form, without the extremely elongate and narrow to clavate chambers. They are here regarded as belonging to *Clavihedbergella simplex* (Morrow).

Types and occurrence: The holotype was from the Eagle Ford shale, one mile north of Lovelace, Hill County, Texas.

Figured (figs. 14–16) and unfigured hypotypes from the Britton clay, Eagle Ford group, lower 5½ feet of the exposure in the north bank of Newton Branch, a short distance northeast of U.S. Highway 287, 3.3 miles west-northwest of the junction with U.S. Highway 67 in Midlothian, Ellis County, Texas. Collected by H. T. and A. R. Loeblich, September 5, 1958.

Figured (fig. 13) and unfigured hypotypes from the Britton clay, Eagle Ford group, basal 10 feet exposed in cut bank of tributary to Mountain Creek, 3.6 miles west of Cedar Hills on road to Mansfield, Dallas County, Texas. Collected by H. T. and A. R. Loeblich, September 4, 1958.

Figured hypotype (fig. 12) from the Atkinson formation, Humble Oil and Refining Co., Bennett and Langsdale well No. 1, core at 3700–3710 feet, Echols Co., Georgia.

Clavihedbergella simplex (Morrow)
Plate 3, figures 11–14

Hastigerinella simplex Morrow, 1934, Jour. Pal., vol. 8, no. 2, p. 198, pl. 30, fig. 6. – Loetterle, 1937, Nebraska, Geol. Survey, 2nd ser., Bull. 12, p. 46, pl. 7, fig. 5. – Cushman, 1946, U. S. Geol. Survey, Prof. Paper, no. 206, p. 148, pl. 61, fig. 10.
Hastigerinella simplicissima Magné and Sigal, 1954, in Cheylan, Magné, Sigal and Grekoff, Soc. Géol. France, Bull., sér. 6, vol. 3 (1953), p. 487, pl. 14, fig. 11a–c.
Schackoina sp. cf. *S. gandolfii* Reichel. – Küpper, 1956, Cushman Found. Foram. Res., Contr., vol. 7, pt. 2, p. 44, pl. 8, fig. 4a–c.

Test free, of medium size, trochospirally coiled, subglobular to elongate chambers forming about two to two and one-half whorls, the early whorl with about five globular chambers, the final whorl with four to six chambers, the last two or three being radially elongate to subclavate; sutures distinct, depressed; wall calcareous, finely perforate, surface finely spinose; aperture an interiomarginal arch extending from the periphery to the umbilicus, with a narrow bordering lip.

Hypotypes range from 0.25 to 0.40 mm. in diameter.

Remarks: Originally described from the Greenhorn limestone of Kansas, and later recorded from the Niobrara formation of Nebraska, the species also occurs in typical form in the Eagle Ford group of Texas. It has also been recorded from the Austin chalk.

Hastigerinella simplicissima Magné and Sigal was said to differ from *H. simpex* in having less elongate chambers and a greater number of chambers. However, topotypes of *H. simplex* show four to six chambers in the final whorl, and *H. simplicissima* was described as having five. The degree of chamber elongation is also quite variable, and the chambers of the average specimen are no more elongated than those of the figured type of *H. simplicissima*, which is therefore here regarded as a synonym of *H. simplex*. Magné and Sigal stated that the species probably occurred in the middle Cenomanian. However, in view of the assemblage in which it occurs, the beds are probably upper Cenomanian in age. Banner and Blow (1959, p. 19) stated that *Hastigerinella simplex* Morrow and *Hastigerinoides simplicissima* Magné and Sigal, 1954 (sic) were considered to belong to *Praeglobotruncana* (*Clavihedbergella*).

Examination of the specimen figured by Küpper (1956) as *Schackoina* sp. cf. *gandolfii* shows no indication of tubulospines, and the specimen to be identical with topotypes of *Clavihedbergella simplex*.

This species was originally described as belonging to *Hastigerinella*, because of the radial elongate chambers, but that dominantly late Cenozoic genus has more definitely elongated chambers, and a more extensive aperture, which is spiroumbilical in character. The present species is extremely variable in both size and degree of chamber elongation.

Types and occurrence: Figured and unfigured hypotypes from the Britton clay, Eagle Ford group, from the basal five feet (figs. 12–14) and unfigured hypotypes from 5 to 10 feet above the base of the exposure in dark blue gray clay exposed in the north bank of Newton Branch, a short distance northeast of U.S. Highway 287, 3.3 miles west-northwest of the junction with U.S. Highway 67, in Midlothian, Ellis County, Texas. Collected by H. T. and A. R. Loeblich, September 5, 1958.

Figured (fig. 11) and unfigured topotypes from the Greenhorn limestone (Hartland shale member) SE ¼ sec. 31, T. 21 S., R. 22 W., north bank of creek about ¼ mile west of the road, Hodgeman Co., Kansas. Collected by Max Furrer.

Genus **Praeglobotruncana** Bermudez, 1952

Praeglobotruncana Bermudez, 1952, Venezuela, Minist. Minas Hidrocarb., Bol. Geol., vol. 2, no. 4, p. 52.

Type species: Globorotalia delrioensis Plummer, 1931. Fixed by original designation.

Test free, trochospiral, biconvex to spiroconvex, umbilicate, periphery rounded to subangular, with a more or less well-developed peripheral keel, which is most prominent in the earlier development; chambers ovate to subangular; sutures on the spiral side radial or curved, depressed to elevated, commonly thickened or beaded, on the umbilical side depressed and radial; wall calcareous, finely perforate, radial in structure, surface smooth to hispid; aperture an interiomarginal, extraumbilical-umbilical arch, bordered by an apertural lip.

Remarks: Regarded as containing both carinate and noncarinate species by Bolli, Loeblich and Tappan (1957), the genus is now restricted to include only those species which have a peripheral keel or poreless margin. The noncarinate species are now placed in *Hedbergella* Bronnimann and Brown.

Praeglobotruncana delrioensis (Plummer)
Plate 6, figures 9–12

Globorotalia delrioensis Plummer, 1931, Texas, Univ., Bull., no. 3101, p. 199, pl. 13, fig. 2. – Frizzell, 1954, Texas, Univ., Bur. Econ. Geol., Rept. Invest. 22, p. 129, pl. 20, fig. 27.

Globorotalia marginaculeata Loeblich and Tappan, 1946, Jour. Pal., vol. 20, no. 3, p. 257, pl. 37, figs. 19–21, text-fig. 4A. – Frizzell, 1954, Texas, Univ., Bur. Econ. Geol., Rept. Invest. 22, p. 129, pl. 20, fig. 29.

Globotruncana stephani Gandolfi. – Mornod, 1950, Eclogae Geol. Helv., vol. 42, no. 2, p. 587, pl. 15, figs. 9a–r, 10–17, text-fig. 10 (1–3). – Hagn and Zeil, 1954, Eclogae Geol. Helv., vol. 47, no. 1, p. 33, pl. 2, fig. 7; pl. 5, figs. 7–8.

Praeglobotruncana delrioensis (Plummer). – Bermudez, 1952, Venezuela, Minist. Minas e Hidrocarb., Bol. Geol., vol. 2, no. 4, p. 52, pl. 7, fig. 1. – Bronnimann and Brown, 1956 (part), Eclogae Geol. Helv., vol. 48, no. 2, p. 53, pl. 21, figs. 8–10; pl. 24, figs. 16, 17; text-figs. 9, 11, 13a–b, d, 15c–f, 16b (not 16c–e). – Bolli, Loeblich and Tappan, 1957, U. S. Nat. Mus., Bull., no. 215, p. 39, pl. 9, fig. 1.

Praeglobotruncana cf. *delrioensis* (Plummer). – Bolli, 1957, U. S. Nat. Mus., Bull., no. 215, p. 55, pl. 12, fig. 4.

PLATE 1

1 *Schackoina primitiva* Tappan
a–c, holotype (Cushman Coll. 25115) from the Grayson formation of Texas, × 125.

2–7 *Schackoina cenomana* (Schacko)
2a–b, hypotype from the Greenhorn limestone (Hartland shale member) of Kansas, × 210. 3–4, hypotypes (USNM P 4644a–b) from the Cenomanian of Germany, × 260. 5–7, hypotypes from the Eagle Ford group (Britton clay) of Texas, showing excellent preservation of this fauna, × 160.

8–10 *Schackoina multispinata* (Cushman and Wickenden)
8a–b, side and edge views of hypotype from the Eagle Ford group (Britton clay) of Texas, × 160. 9a–b, 10a–b, side and edge views of hypotypes from the Greenhorn limestone (Hartland shale member) of Kansas, × 210.


1a
1c
1b
2b
2a
3
4a
4c
4b
5
6a
6c
6b
8b
9b
9a
8a
10a

Praeglobotruncana (Praeglobotruncana) cf. *stephani* (Gandolfi). – Banner and Blow, 1959, Palaeontology, vol. 2, pt. 1, pl. 3, fig. 4.

Not *Globorotalia delrioensis* Plummer. – Tappan, 1940, Jour. Pal., vol. 14, no. 2, p. 123, pl. 19, fig. 14. – Loeblich and Tappan, 1946, Jour. Pal., vol. 20, no. 3, p. 257, text-fig. 4B.

Not *Praeglobotruncana delrioensis* (Plummer). – Ziegler, 1957, Neues Jahrb. Geol. Pal., Monatsheft, vol. 5, p. 199.

Test free, low trochospiral, biconvex, umbilicate, periphery rounded to slightly subangular, early whorls with a narrow nodose keel which dies out in the later chambers; abut two and one-half whorls present, with five and one-half to seven chambers in the final whorl; sutures distinct, curved on the spiral side where they are slightly thickened and even nodose, straight, radial and depressed on the umbilical side; wall calcareous, finely perforate, surface spinose to nodose, most prominently in the peripheral region; aperture an interiomarginal, extraumbilical-umbilical arch extending to the periphery, with a narrow bordering lip. Topotypes range from 0.26 to 0.45 mm. in greatest diameter.

Remarks: This species has been confused in the past with the younger species *Praeglobotruncana stephani* (Gandolfi), and has even been regarded as synonymous by Bronnimann and Brown (1956, p. 531), Ziegler (1957, p. 199) and Banner and Blow (1959, p. 8). The two species are quite distinct morphologically, as can be seen by an examination of type material, such as the topotypes herein illustrated. *Praeglobotruncana stephani* is planoconvex and has angular to rhomboidal chambers, and is somewhat larger in size. It also occurs higher in the Cenomanian than does the nearly wholly biconvex *P. delrioensis*. There is considerable variation in the amount of compression of the present species, with all gradations from the somewhat compressed and subangular tests, like the holotype (and the topotype here shown in figure 10), to the almost globular chambered forms described as *Globorotalia marginaculeata*, but now considered conspecific. *Praeglobotruncana delrioensis* is probably ancestral to *P. stephani*. In the type area in Texas, it occurs in Albian and lower Cenomanian strata (upper Washita group) and the younger *P. stephani* occurs in the Eagle Ford group. This lineage excellently demonstrates several of the evolutionary trends suggested by Bronnimann and Brown (1956, p. 515) in that there is an increase in size (*P. stephani* being larger than *P. delrioensis*), an increased angularity of chambers from the rounded ones of adult *P. delrioensis* to the subrhomboidal ones of the planoconvex *P. stephani*, and an increase in the height of coiling.

As noted by Bronnimann and Brown (1956, p. 532) *Globorotalia marginaculeata* Loeblich and Tappan is a synonym of the present species, and the specimens referred to *G. delrioensis* by Tappan (1940) and Loeblich and Tappan (1946) are actually *Rotalipora*. These latter specimens are herein placed in *Rotalipora evoluta* Sigal.

Praeglobotruncana delrioensis occurs in the lower Cenomanian and upper Albian (Washita group) of Texas and Oklahoma, and in equivalent strata in Trinidad, and in Switzerland. It also occurs in submarine cores on the Blake Plateau, north of the Bahamas.

Types and occurrence: Topotype of fig. 9 (USNM P 4481) and topotype of fig. 10, and unfigured topotypes from the Del Rio clay, on the west bank of Shoal Creek, just south of the 34th Street Bridge, in Austin, Travis Co., Texas. Collected by H. T. and A. R. Loeblich.

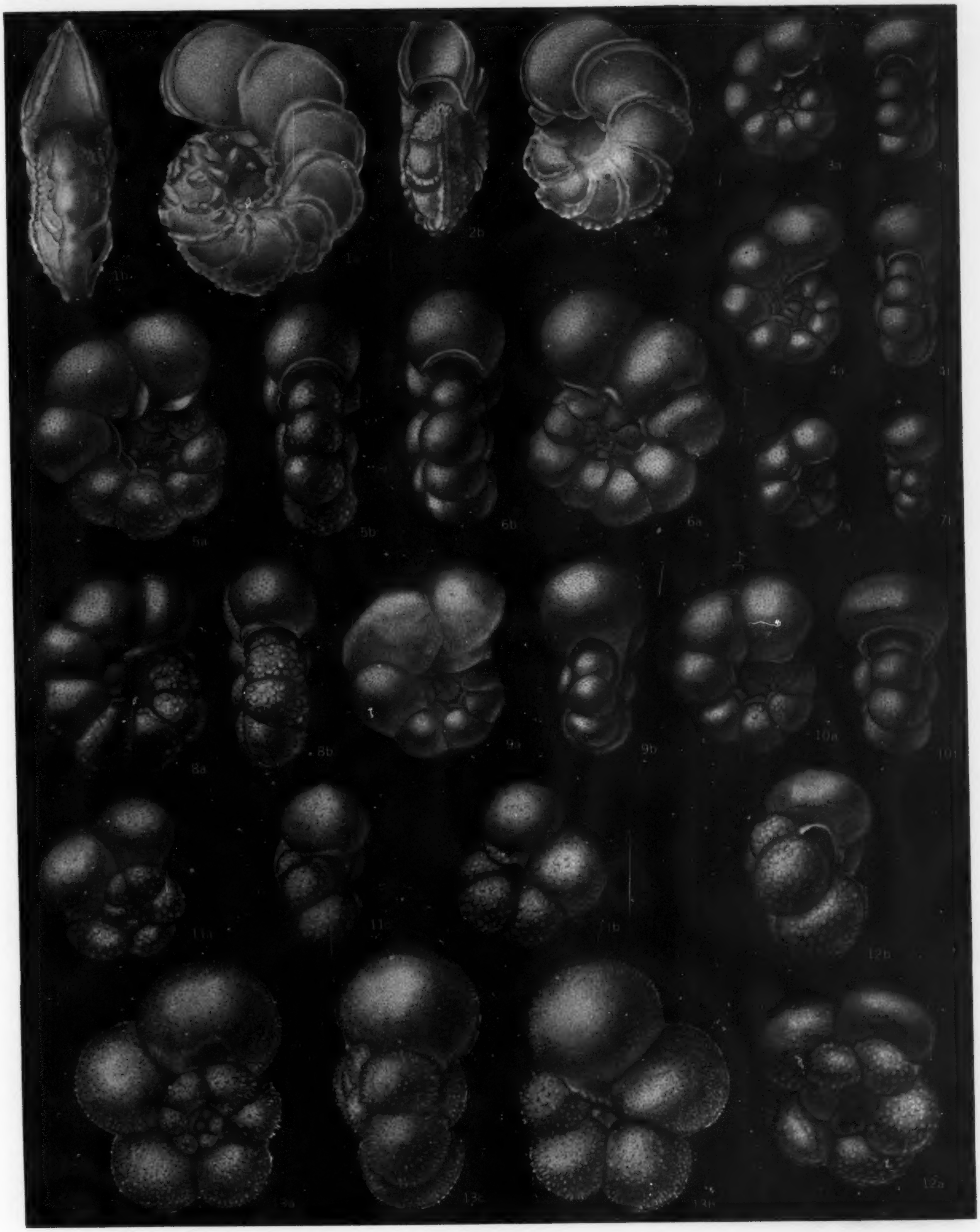
PLATE 2

1–2 *Planomalina buxtorfi* (Gandolfi)
2a–b, side and edge views of hypotype of *P. apsidostroba* Loeblich and Tappan, now regarded as a synonym of *P. buxtorfi*, from the Paw Paw formation (upper Albian) of Texas, × 145. 1a–b, side and edge views of holotype of *P. apsidostroba*, Cushman Coll. 45667, from the Main Street formation (Upper Albian) of Texas, × 110.

3–7 *Globigerinelloides eaglefordensis* (Moreman)
4a–b, hypotype from the Del Rio clay of Texas. 7a–b, hypotype from the Cenomanian, submarine core on the Blake Plateau. 3a–b, hypotype from the Grayson formation of Texas. 5a–6b, hypotypes from the Eagle Ford group (Britton clay) of Texas. Figs. 3, 4, 7, × 100; figs. 5, 6, × 185.

8–10 *Globigerinelloides bentonensis* (Morrow)
8a–b, hypotype from the Cenomanian, submarine core on the Blake Plateau. 9a–b, topotype from the Greenhorn limestone (Hartland shale member) of Kansas. 10a–b, hypotype from the Grayson formation of Texas, × 105.

11–13 *Hedbergella delrioensis* (Carsey)
11a–12c, topotypes from the Del Rio clay of Texas. 13a–c, hypotype from the Grayson formation of Texas, × 100.



Unfigured hypotype from the Del Rio clay on Barton Springs Road, just east of Barton Creek, in cut of branch road which turns south from the Barton Springs Road, in Austin, Travis Co., Texas. Collected by H. T. and A. R. Loeblich.

Unfigured hypotypes from the Grayson formation, Grayson Bluff on Denton Creek, 3½ miles northeast of Roanoke, Denton Co., Texas. Collected by H. T. and A. R. Loeblich.

Unfigured hypotypes from the Grayson formation, in a northwest-facing slope ¾ mile due east of Burleson, 0.2 mile northeast of the old Burleson-Alvarado road, Johnson Co., Texas. Collected by H. T. and A. R. Loeblich.

Unfigured hypotypes from the Maness formation, middle portion of core at 3635–3665 feet in Shell Oil Co., S. T. Stephens No. 1, Henderson Co., (La Rue area), Texas.

Figured hypotype (fig. 12) from a depth of 90–100 cm., and hypotype of figure 11 from a depth of 170–175 cm., from the Cenomanian, Lamont Geological Observatory Core A-167-25, on escarpment of Blake Plateau, lat. 28°52′ N., long. 76°47′ W, north of the Bahama Islands, and unfigured hypotypes from depth of 70–80 cm., 80–90 cm., 90–100 cm., 110–120 cm. and 140–150 cm. in the same core.

Praeglobotruncana stephani (Gandolfi)
Plate 6, figures 1–8

Globotruncana stephani GANDOLFI, 1942, Riv. Ital. Pal., ann. 48, mem. 4, p. 130, pl. 3, figs. 4–5; pl. 4, figs. 36–37, 41–45; pl. 6, figs. 4, 6; pl. 9, figs. 5, 8; pl. 13, fig. 5; pl. 14, fig. 2. – BOLLI, 1945, Eclogae Geol. Helv., vol. 37, no. 2, p. 224, text-fig. 1 (Nos. 3–4), pl. 9, fig. 2. – CITA, 1948, Riv. Ital. Pal. Strat., vol. 54, no. 3, p. 17, pl. 4, fig. 6. – AYALA, 1954, Asoc. Mex. Geol. Petrol., Bol., vol. 6, no. 11–12, p. 411, pl. 11, fig. 2.

Globotruncana apenninica var. β, GANDOLFI, 1942, Riv. Ital. Pal., vol. 48, no. 4, p. 119, text-fig. 41 (2a–b).

Globorotalia californica CUSHMAN AND TODD, 1948, Cushman Lab. Foram. Res., Contr., vol. 24, pt. 4, p. 96, pl. 16, figs. 22–23.

Globotruncana (Globotruncana) stephani Gandolfi. – REICHEL, 1950, Eclogae Geol. Helv., vol. 42, no. 2, p. 608, pl. 16, fig. 6, pl. 17, fig. 6.

Globotruncana stephani Gandolfi var. *turbinata*. – REICHEL, 1950, Eclogae Geol. Helv., vol. 42, no. 2, p. 609. – MORNOD, 1950, Eclogae Geol. Helv., vol. 42, no. 2, p. 589, text-fig. 11 (1–3), pl. 15, figs. 18–20. – HAGN AND ZEIL, 1954, Eclogae Geol. Helv., vol. 47, no. 1, p. 34, pl. 2, fig. 2, pl. 5, figs. 3–4. – AYALA, 1954, Asoc. Mex. Geol. Petrol., Bol., vol. 6, no. 11–12, p. 412, pl. 11, fig. 3.

Globotruncana (Globotruncana) stephani Gandolfi var. *turbinata* Reichel. – BOLLI in CHURCH, 1952, Cushman Found. Foram. Res., Contr., vol. 3, pt. 2, p. 70, text-fig. 1 (bottom).

Rotundina stephani (Gandolfi). – SUBBOTINA, 1953, Trudy Vses. Neft. Naukno-Issledov. Geol.-Razved. Inst., n. ser., 76, p. 165, pl. 2, figs. 5–7, pl. 3, figs. 1–2.

Globotruncana (Rotundina) aumalensis (Sigal). – KÜPPER, 1955, Cushman Found. Foram. Res., Contr., vol. 6, pt. 3, p. 116, pl. 18, fig. 5.

Globotruncana (Rotundina) stephani stephani (Gandolfi). – KÜPPER, 1955, Cushman Found. Foram. Res., Contr., vol. 6, pt. 3, p. 116, pl. 18, fig. 6.

Globotruncana (Praeglobotruncana) stephani (Gandolfi) *turbinata* Reichel. – KÜPPER. 1956, Cushman Found. Foram. Res., Contr., vol. 7, pt. 2, p. 43, pl. 8, fig. 1.

Globotruncana (Praeglobotruncana) renzi (Thalmann and Gandolfi) subsp. *primitiva* KÜPPER, 1956, Cushman Found. Foram. Res., Contr., vol. 7, pt. 2, p. 43, pl. 8, fig. 2a–c.

Praeglobotruncana delrioensis (Plummer). – BRONNIMANN AND BROWN, 1956 (part), Eclogae Geol. Helv., vol. 48, no. 2, p. 531 (not pl. 21, figs. 8–10, pl. 24, figs. 16–17, text-figs. 9, 11, 13a–b, d, 15c–f, 16b). – ZIEGLER, 1957 (part), Neues Jahrb. Geol. Pal., Monatsheft, vol. 5, p. 199.

Praeglobotruncana delrioensis (Plummer) var. *turbinata* (Reichel). – BRONNIMANN AND BROWN, 1956, Eclogae Geol. Helv., vol. 48, no. 2, p. 532, text-fig. 16c–e. – ZIEGLER, 1957, Neues Jahrb. Geol. Pal., Monatsheft, vol. 5, p. 199.

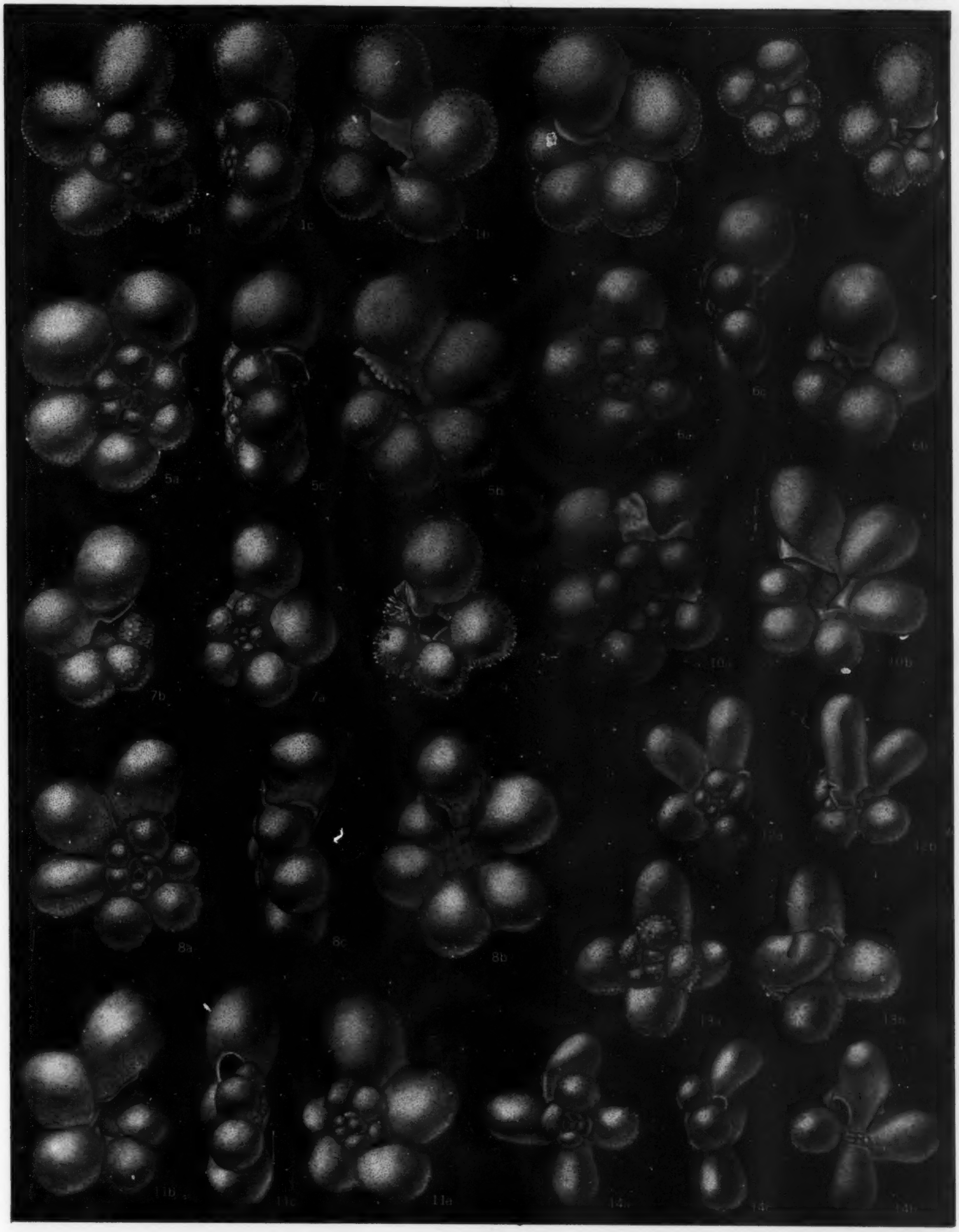
Globotruncana (Globotruncana?) stephani turbinata Reichel. – GANDOLFI 1957, Cushman Found. Foram. Res., Contr., vol. 8, pt. 2, p. 62, pl. 9, fig. 4.

PLATE 3

All figures are × 100

1–10 *Hedbergella amabilis* Loeblich and Tappan, n. sp.
1a–c, holotype, and 2–5c, paratypes, from the Eagle Ford group, Britton clay of Dallas Co., Texas, showing variation in size, strongly constricted sutures, finely spinose wall and distinct apertural lip. 6a–c, paratype from a Cenomanian submarine core on the Blake Plateau. 7a–8c, paratypes from the subsurface Atkinson formation of Georgia. 9–10b, paratypes from the Britton clay of Ellis Co., Texas.

11–14 *Clavihedbergella simplex* (Morrow)
11a–c, topotype from the Greenhorn limestone (Hartland shale member) with moderately elongate chambers. 12a–14c, hypotypes from the Eagle Ford group, Britton clay of Texas, showing characteristic radial elongate chambers.



Praeglobotruncana stephani (Gandolfi). – BOLLI, LOEBLICH AND TAPPAN, 1957, U. S. Nat. Mus., Bull., no. 215, p. 39, pl. 9, fig. 2. – BYKOVA, VASILENKO, VOLOSHINOVA, MIATLIUK, AND SUBBOTINA, 1959. Osnovy Paleontologii, text-fig. 687.

Praeglobotruncana (Praeglobotruncana) stephani (Gandolfi). – BANNER AND BLOW, 1959, Palaeontology, vol. 2, pt. 1, p. 3, text-fig. 1a (does not include in synonymy, as p. 8, *Globorotalia delrioensis* Plummer).

Globotruncana kuepperi THALMANN, 1959, Cushman Found. Foram. Res., vol. 10, pt. 4, p. 130.

Not *Globotruncana stephani* Gandolfi. – MORNOD, 1950, Eclogae Geol. Helv., vol. 42, no. 2, p. 587, pl. 15, figs. 9–17, text-fig. 10 (nos. 1–3). – HAGN AND ZEIL, 1954, Eclogae Geol. Helv., vol. 47, no. 1, p. 33, pl. 2, fig. 7, pl. 5, figs. 7–8.

Not *Globotruncana (Rotundina) californica* Cushman and Todd. – KÜPPER, 1955, Cushman Found. Foram. Res., Contr., vol. 6, pt. 3, p. 116, pl. 18, fig. 7.

Not *Praeglobotruncana (Praeglobotruncana)* cf. *stephani* (Gandolfi). – BANNER AND BLOW, 1959, Palaeontology, vol. 2, pt. 1, pl. 3, fig. 4.

Test free, trochospiral; all chambers of the two to three whorls visible on the strongly convex spiral side, only the five to six, more rarely up to eight chambers of the final whorl visible on the flattened to moderately convex umbilical side, early chambers subrounded, later ones slightly depressed on the spiral side and tending to become subangular, umbilicus narrow; sutures distinct, depressed, gently curved backwards towards the periphery on the spiral side, nearly radial on the umbilical side; wall calcareous, finely perforate, surface finely spinose, most prominently on the spiral side, a beaded peripheral keel bordering the early whorls but less distinct in the last two or three chambers, the keel of earlier whorls remaining visible on the spiral side just above the sutures; aperture an interiomarginal arch extending from the umbilicus about half the distance to the periphery, bordered by a broad spatulate lip which may overhang somewhat the umbilical region, but is commonly broken. Hypotypes range from 0.35 to 0.43 mm. in diameter.

Remarks: Originally described as *Globotruncana*, this species was later made the type species of *Rotundina* Subbotina, a junior synonym of *Praeglobotruncana* Bermudez.

Due in part to its variability, this species has been described under various names. Examination of a suite of specimens from each of the different areas shows that all gradations occur between the extremes described as *Globotruncana stephani* and the variety *turbinata*. The larger specimens, with more chambers per whorl in the final whorl and a higher spire resulting from the greater number of whorls, were placed in the "variety" *turbinata*, the smaller and younger specimens were regarded as typical *stephani*. As these are only functions of the age of the specimen, and as both extremes occur together, with an identical geographic and geologic range, no useful purpose is served by the retention of two names.

Bronnimann and Brown (1956, p. 531) noted the synonymy of some of the above-mentioned names, but also considered *Praeglobotruncana stephani* to be a synonym

PLATE 4

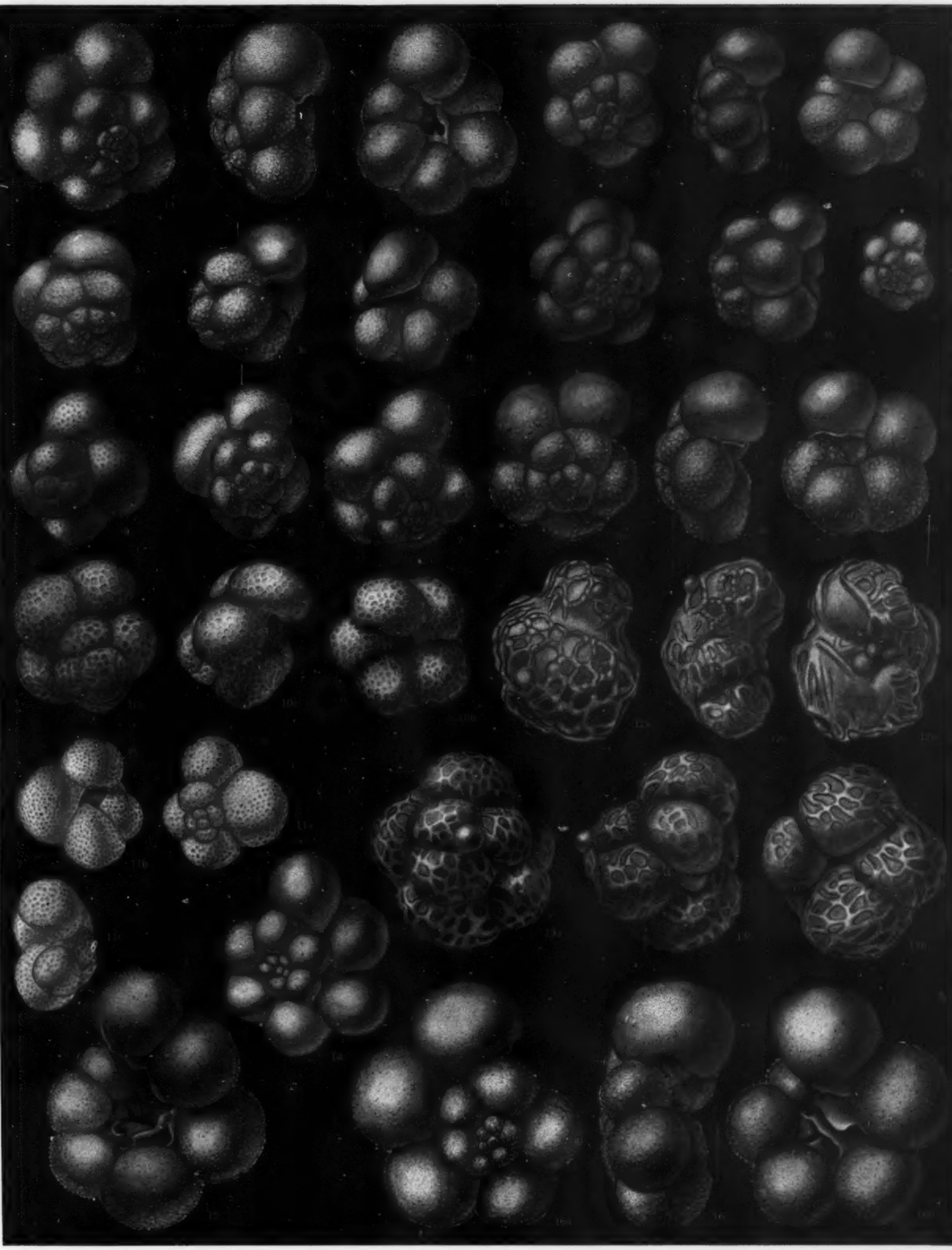
All figures × 75, except figure 11, which is × 45

1–8 *Hedbergella brittonensis* Loeblich and Tappan, n. sp.
1a–c, holotype, from the Eagle Ford group, Britton clay of Texas. 2a–3c, paratypes from the Greenhorn limestone, Hartland shale member, of Kansas. 4a–7, paratypes from the Eagle Ford group, Britton clay of Texas, showing variation in height of spire, size of test and number of chambers per whorl. 8a–c, paratypes from the subsurface Atkinson formation of Georgia.

9–11 *Hedbergella washitensis* (Carsey)
9–10c, hypotypes from the Cenomanian, submarine core on the Blake Plateau. 11a–c, topotype from the Del Rio clay of Texas, × 45.

12–13 *Hedbergella hiltermanni* Loeblich and Tappan, n. sp.
12a–c, paratype. 13a–c, holotype. Both specimens show the very coarsely reticulate surface and large size of this species; from the basal Cenomanian of Germany.

14–16 *Ticinella aprica* Loeblich and Tappan, n. sp.
14, paratype from the Eagle Ford group, Britton clay, of Texas, showing low spire. 15, paratype from the Eagle Ford group, Arcadia Park shale, of Texas, with broad open umbilicus with characteristic ragged appearing margin, due to the distinctive apertural lips, with secondary sutural apertures at posterior margin of chambers. 16a–c, holotype, from the Arcadia Park shale, Eagle Ford group.



of *P. delrioensis* (Plummer). Reichel (1957, p. 94) regarded these as closely related, but distinct species, and we also recognize two species, one species being *P. delrioensis* and so-called by Bronnimann and Brown, and the other, *P. stephani* including those forms regarded by Bronnimann and Brown as *P. delrioensis* var. *turbinata*. As shown in the present figures, the middle and upper Cenomanian species, *P. stephani*, is more high spired, tending to become planoconvex, whereas the lower Cenomanian species *P. delrioensis* is nearly equally biconvex, with rounded to ovate chambers instead of the semiangular rhomboidal chambers of *P. stephani*. Some references to *P. stephani* are actually *P. delrioensis*, however (as is here noted in the synonymies). In addition to the above-mentioned synonyms, *Globorotalia californica* Cushman and Todd is also a synonym of *P. stephani*. Bolli (in Church, 1952, p. 70) had reported *Globotruncana stephani* var. *turbinata* from the California Cretaceous (Calera limestone), and stated that it was probably of middle or upper Cenomanian age. Küpper (1955, p. 116; 1956, p. 43) also reported the subspecies from the "Franciscan series" and "Antelope Shale" (Cenomanian) of California. Küpper (1955, p. 116) considered *Globigerina almadenensis* Cushman and Todd to be a synonym of the present species and recognized *Globorotalia californica* Cushman and Todd as a distinct species. An examination of the holotypes of these California species shows that *G. californica* Cushman and Todd is identical to *P. stephani*. The specimen illustrated by Küpper as belonging to *G.* (*Rotundina*) *californica* is *Ticinella aprica* Loeblich and Tappan, n. sp. *Globigerina almadenensis* differs in having rounded chambers, rather than being basally truncated and is a synonym of *Hedbergella trocoidea* (Gandolfi).

An examination of the type of *Globotruncana* (*Praeglobotruncana*) *renzi* (Thalmann and Gandolfi) subsp. *primitiva* Küpper shows it to be a crushed specimen of *Praeglobotruncana stephani*. As the subspecific name was a homonym of *Globotruncana* (*Globotruncana*) *ventricosa* White subsp. *primitiva* Dalbiez, 1955, it had been renamed as *Globotruncana kuepperi* Thalmann, 1959, both names thus being included in the synonymy of *P. stephani*.

The present species is known from Cenomanian strata of Switzerland, Italy, Russia and Bavaria and occurs in the Cenomanian of California, Greenhorn limestone of Kansas and the Eagle Ford (Britton clay) of Texas. The sectioned specimen, referred to *P. stephani* (Gandolfi), illustrated from the upper Cenomanian of Tanganyika by Banner and Blow (1959, pl. 3, fig. 4) has the appearance of *Praeglobotruncana delrioensis* Plummer, and not that of the present species.

Types and occurrence: Figured (fig. 1) topotype (USNM P 4848) of *Praeglobotruncana stephani* (Gandolfi) from the Cenomanian, Breggia number 56, Canton Ticino, Switzerland, and (fig. 2) of *P. stephani* "*turbinata*," from Breggia bed 57. Both identified by M. Reichel.

Figured hypotype (fig. 3) (similar to and compared with the type specimen of *Globorotalia californica* Cushman and Todd) and unfigured hypotypes from the Cenomanian in Clark Valley, cen. sec. 32, T. 20 N., R. 5 W., Fruto Quadrangle, Glenn Co., California.

Unfigured hypotype from the Britton clay, Eagle Ford group, 10 to 15 feet above the base of the exposure, and figured (figs. 7–8) and unfigured hypotypes from 15 to 21 feet above the base, in cut bank of a tributary to Mountain Creek, 3.6 miles west of Cedar Hills on the road to Mansfield, Dallas Co., Texas. Collected by H. T. and A. R. Loeblich, September 4, 1958.

Unfigured hypotypes from the Britton clay, Eagle Ford group, 16 to 21 feet above the base of the exposure, just east of California Crossing of Elm Fork of the Trinity

PLATE 5

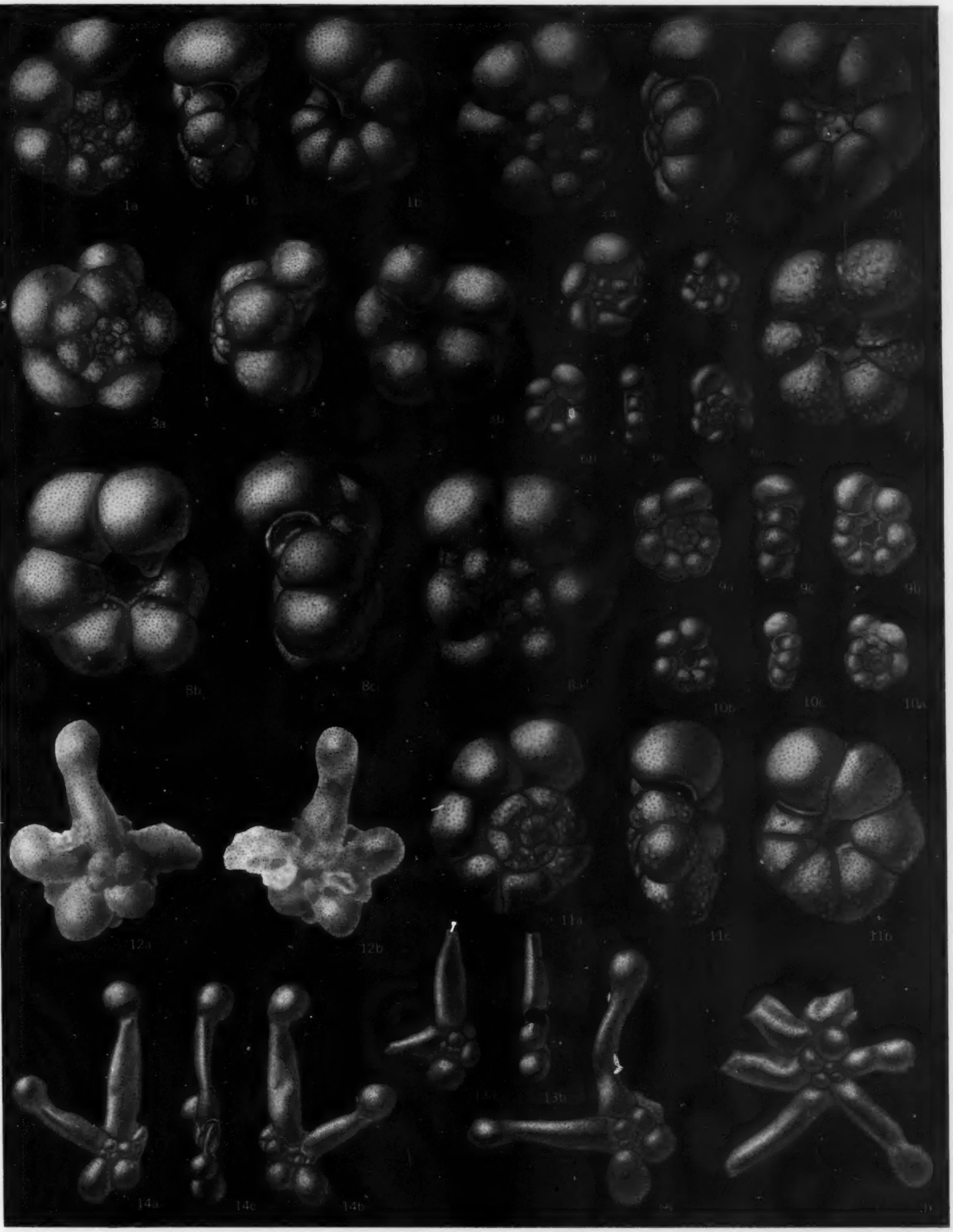
Figures 7, 8, 11 × 185; all others, × 100

1–2 *Hedbergella trocoidea* (Gandolfi)
1a–2c, hypotypes from the Cenomanian, submarine core on the Blake Plateau.

3 *Hedbergella portsdownensis* (Williams-Mitchell)
3a–c, hypotype from the Cenomanian of Germany.

4–11 *Hedbergella planispira* (Tappan)
4–6c, 9a–10c, hypotypes from the Eagle Ford group (Britton clay) of Texas. 7–8c, topotypes from the Grayson formation of Texas. 11a–c, hypotype from the Cenomanian, submarine core on the Blake Plateau.

12–16 *Clavihedbergella moremani* (Cushman)
12a–b, hypotype from the subsurface Atkinson formation of Georgia. 13a–b, hypotype from the Eagle Ford group (Britton clay) of Dallas Co., Texas. 14a–16, hypotypes from the Eagle Ford group (Britton clay) of Ellis Co., Texas, showing the extremely elongated clavate chambers of the final whorl.



River, 1.0 mile north of the University of Dallas campus, about ¼ mile west of the bridge of Wildwood Road over Elm Fork, west of Dallas, Dallas Co., Texas. Collected by H. T. and A. R. Loeblich, September 5, 1958.

Figured (figs. 4–6) and unfigured hypotypes from the Greenhorn limestone (Hartland shale member), SE¼ sec. 31, T. 21 S., R. 22 W., north bank of creek, about ¼ mile west of road, Hodgeman Co., Kansas. Collected by Max Furrer.

Subfamily **Rotaliporinae** Sigal, 1958

Rotaliporidae SIGAL, 1958 (part), Soc. Géol. France, C. R. Somm., no. 12, p. 264.
Rotaliporinae Sigal. – BANNER AND BLOW, 1959 (part), Palaeontology, vol. 2, pt. 1, p. 8.

Type Genus: Rotalipora Brotzen, 1942.

Coiling of test trochospiral, chambers angular to ovate or spherical; wall calcareous, perforate, radial in structure; primary aperture extraumbilical-umbilical, with relatively prominent bordering lip, secondary sutural apertures on the umbilical side, opening into the chambers at their posterior umbilical margin.

Range: Albian to Cenomanian, Turonian?

Genus **Ticinella** Reichel, 1950

Ticinella REICHEL, 1950, Eclogae Geol. Helv., vol. 42, no. 2, p. 600.

Type species: Anomalina roberti Gandolfi, 1942. Fixed by original designation and monotypy.

Test free, trochospiral, biconvex to planoconvex, umbilicate, periphery rounded, and lacking keel or poreless margin, chambers ovate; sutures on spiral side curved, depressed to elevated, on umbilical side flush to depressed, radial or slightly curved; wall calcareous, perforate, radial in structure, surface smooth to spinose; primary aperture interiomarginal, extraumbilical-umbilical, and may be bordered above by a lip, secondary sutural apertures on the umbilical side, commonly one per suture, more rarely two or more, and each may be bordered by a narrow lip, which in some specimens may be sufficiently large as to give the appearance of a cover plate, although not as extensive as the umbilical tegilla of the Globotruncanidae.

Remarks: Ticinella was regarded as a synonym of *Rotalipora* Brotzen by Bolli, Loeblich and Tappan (1957). Because of the absence of poreless margin or keel in *Ticinella*, we now regard these genera as distinct. *Ticinella* occurs in Albian and Cenomanian strata.

PLATE 6

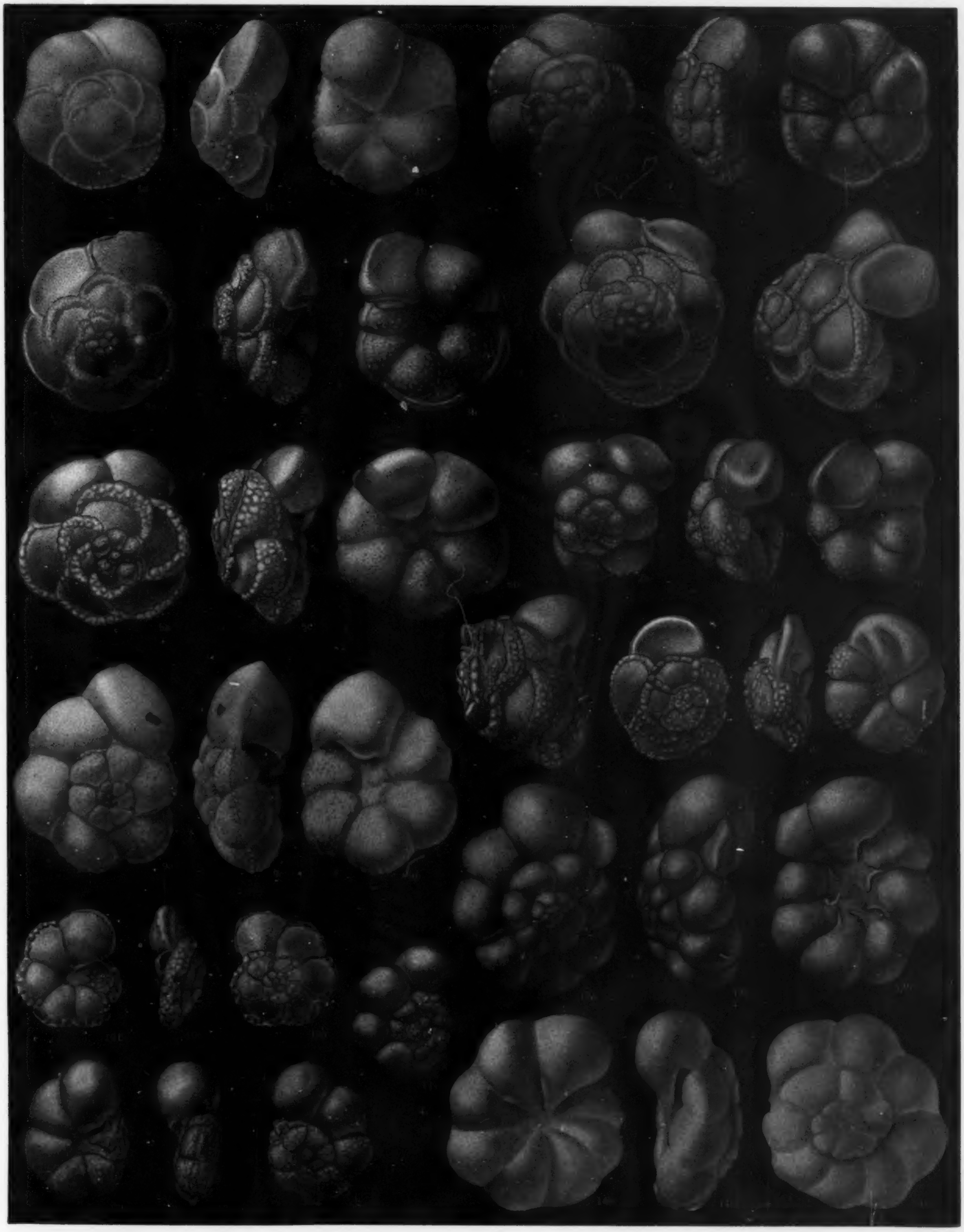
All figures × 75 unless otherwise noted

1–8 *Praeglobotruncana stephani* (Gandolfi)
1a–c, topotype from the Cenomanian of Switzerland, showing characteristic form of the species, × 70. 2a–c, topotype of *Globotruncana stephani* var. *turbinata* Reichel from the Cenomanian of Switzerland showing very slightly more elevated spire. 3a–c, hypotype similar to holotype of *Globorotalia californica* Cushman and Todd, from the Cenomanian of California. 4a–6, hypotypes from the Greenhorn limestone (Hartland shale member) of Kansas, showing intraspecific variation in height of spire. 7a–8c, hypotypes from the Eagle Ford group (Britton clay) of Texas, showing low spire in small specimen and beginning of more elevated spire in larger specimen.

9–12 *Praeglobotruncana delrioensis* (Plummer)
9a–c, topotype (USNM P 4481), showing moderate chamber inflation, × 110. 10a–c, topotype showing greater amount of angularity, similar to the holotype. 11–12c, hypotypes with somewhat inflated chambers and poorly defined keel, from the Cenomanian, submarine core on the Blake Plateau.

13 *Ticinella multiloculata* (Morrow)
13a–c, topotype from the Greenhorn limestone (Hartland shale member), showing nonkeeled, globular chambers and secondary sutural apertures, × 60.

14 *Ticinella roberti* (Gandolfi)
14a–c, topotype (USNM P 4829) from the Cenomanian of Switzerland, × 110.



Ticinella aprica Loeblich and Tappan, **new species**
Plate 4, figures 14–16

Globotruncana (Rotundina) californica (Cushman and Todd). – KÜPPER, 1955, Cushman Found. Foram. Res., Contr., vol. 6, pt. 3, p. 116, pl. 18, fig. 7.

Test free, low trochospiral coil of two and one-half whorls, broadly umbilicate, periphery rounded, peripheral outline lobulate, five to six globular chambers in the final whorl, rarely seven, chambers increasing gradually in size as added; sutures distinct, strongly constricted, radial, straight; wall calcareous, finely perforate, surface coarsely hispid, but spines less prominent on final chambers; primary aperture an interiomarginal, umbilical-extraumbilical arch, oriented somewhat toward the plane of coiling, a narrow bordering rim flaring at the backward margin into a prominent lip, behind which is a secondary opening into the chamber, just anterior to the adjacent suture.

Greatest diameter of holotype 0.63 mm.; thickness 0.33 mm. Paratypes range from 0.45 to 0.68 mm. in maximum diameter.

Remarks: This species differs from *Ticinella multiloculata* (Morrow) in having fewer chambers per whorl, in having globular rather than slightly subangular chambers, and in the coarsely hispid surface.

The specific name is from the Latin *apricus*, lying open, uncovered, and refers to the open umbilicus and exposed secondary apertures.

Types and occurrence: Holotype (fig. 16), figured (fig. 15) and unfigured paratypes from the Arcadia Park shale, road cut on north side of U.S. Highway 80, just east of intersection with Loop 12, west of Dallas, Dallas Co., Texas. Collected by H. T. and A. R. Loeblich, September 5, 1958. Figured paratype (fig. 14) from the lowest five feet in the cut bank of the tributary to Mountain Creek, 3.6 miles west of Cedar Hills on road to Mansfield, Dallas Co., Texas. Collected by H. T. and A. R. Loeblich.

Ticinella multiloculata (Morrow)
Plate 6, figure 13

Globorotalia? multiloculata MORROW, 1934, Jour. Pal., vol. 8, p. 200, pl. 31, figs. 3, 5. – Cushman, 1946, U. S. Geol. Survey, Prof. Paper, no. 206, p. 153, pl. 62, figs. 10–11.
Rugoglobigerina multiloculata (Morrow). – BERMUDEZ, 1952, Venezuela, Minist. Minas e Hidrocarb., Bol. Geol., vol. 2, no. 4, pl. 22, fig. 1.
Thalmanninella multiloculata (Morrow). – BRONNIMANN AND BROWN, 1956, Eclogae Geol. Helv., vol. 48, no. 2, p. 534, pl. 20, figs. 1–3.
Not *Globorotalia? multiloculata* Morrow. – MALLORY, 1959, Lower Tert. Biostrat. Calif. Coast Ranges, p. 256, pl. 34, fig. 11a–c.

Test free, relatively large, trochospirally coiled in two to three whorls, spiral side convex, opposite side broadly umbilicate, peripheral outline lobulate; globular chambers increasing gradually in size, from six to nine in the final whorl, commonly eight; sutures distinct, depressed, radial to slightly oblique, straight to gently curved; wall calcareous, finely perforate, surface roughened, varying from almost smooth to finely papillose, the strongest ornamentation being on the umbilical side near the umbilical region, aperture a low, interiomarginal, extraumbilical-umbilical arch, with a narrow bordering lip, supplementary sutural apertures very large, situated almost at the umbilical margin of the chambers, and with distinctly arched lips.

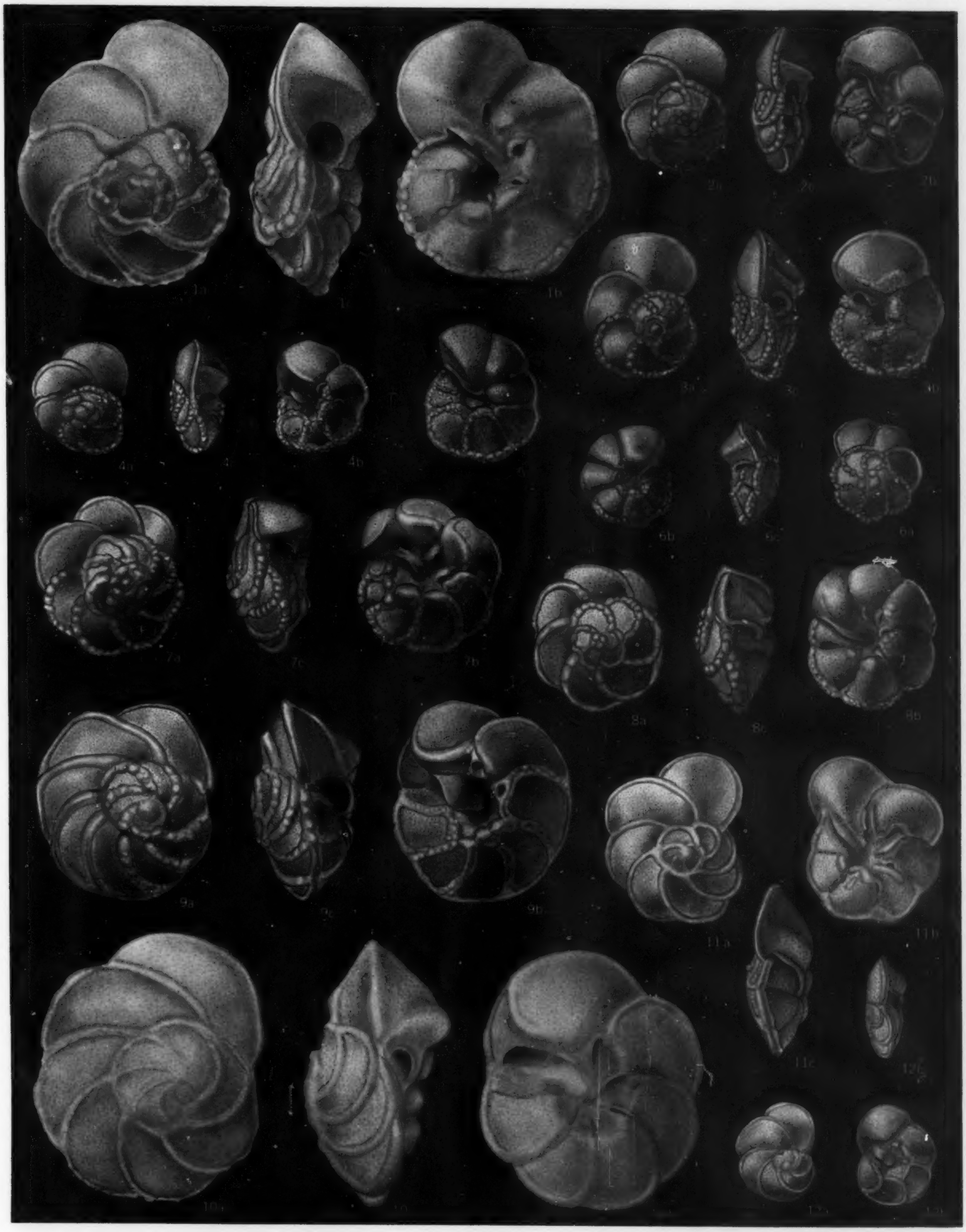
Greatest diameter of figured topotype 0.67 mm., greatest thickness 0.37 mm. Other specimens range from 0.41 to 0.62 mm. in maximum diameter.

PLATE 7

1–4 *Rotalipora evoluta* Sigal
1a–c, hypotype (USNM P 4873) originally referred to *R.* cf. *R. appenninica* (O. Renz), but now regarded as *R. evoluta*, × 100. 2a–c, hypotype, × 60. Both from the Del Rio clay of Texas. 3a–4c, hypotypes from the Grayson formation of Texas, × 60, showing somewhat enlarged final chamber.

5–10 *Rotalipora greenhornensis* (Morrow)
5–6c, hypotypes from the Cenomanian, submarine core on the Blake Plateau. 7a–c, hypotype from the Cenomanian of California, similar to the specimens described as *Globorotalia decorata* Cushman and Todd. 8a–c, hypotype from the Cenomanian of Germany, such as was referred to *Rotalipora globotruncanoides* Sigal, all × 60. 9a–c, topotype from the Greenhorn limestone (Hartland shale member) of Kansas, × 80. 10a–c, topotype (USNM P 3930) of *Thalmanninella brotzeni* Sigal, from the Cenomanian of Algeria, × 100.

11–12 *Rotalipora appenninica* (O. Renz)
11a–12c, hypotypes from the subsurface Maness formation of Texas, × 45.



Remarks: This species has been placed in a different genus by almost every author who has studied it. Originally referred questionably to *Globorotalia* it was later placed in *Rugoglobigerina*, but the presence of sutural supplementary apertures and absence of tegilla preclude such assignment. Bronnimann and Brown (1956, p. 535) recognized the supplementary apertures and placed the species in *Thalmanninella*. Bolli, Loeblich and Tappan (1957, p. 41) regarded *Thalmanninella* and *Ticinella* as junior synonyms of *Rotalipora*, but the present species is here placed in the genus *Ticinella*, which is now differentiated from *Rotalipora* by its nonkeeled periphery.

Ticinella roberti (Gandolfi) is similar to the present species in general appearance, globular chambers, number of chambers per whorl, presence of two to three whorls of chambers and low trochospiral coil. However, the present species has a very broad umbilical area, and the large open-arched supplementary apertures are almost umbilical in position rather than along the sutures as in *T. roberti*. *Ticinella roberti* is also somewhat more compressed, with the umbilical side of the chambers appearing almost wedge-shaped.

Mallory (1959, p. 256) recorded this stratigraphically restricted Cenomanian species in the Ynesian, Bulitian, Ulatisian and Narisian stages (middle Paleocene to uppermost Eocene) in California. The species figured by Mallory actually bears little resemblance to *Ticinella multiloculata* and is generically unrelated, as it lacks the characteristic supplementary apertures of this Cretaceous form. The specimen figured by Mallory (pl. 34, fig. 11) is a true *Globorotalia*, and judging from the range given for the "species" in California, several species of true *Globorotalia* may in fact be represented.

Types and occurrence: Figured and unfigured topotypes from the Greenhorn limestone (Hartland shale member), SE¼ sec. 31, T. 21 S., R. 22 W., north bank of creek, about ¼ mile west of road, Hodgeman Co., Kansas. Collected by Max Furrer.

Ticinella roberti (Gandolfi)
Plate 6, figure 14

Anomalina roberti Gandolfi, 1942, Riv. Ital. Pal., vol. 48, no. 4, p. 100, pl. 2, fig. 2; pl. 4, figs. 4–7, 20; pl. 5, fig. 1; pl. 13, figs. 3, 6.

Globotruncana (Ticinella) roberti (Gandolfi). – Reichel, 1950, Eclogae Geol. Helv., vol. 42, no. 2, p. 600, text-figs. 1a–c, 2a–c, pl. 16, fig. 1; pl. 17, fig. 1.

Rotalipora roberti (Gandolfi). – Bolli, Loeblich and Tappan, 1957, U. S. Nat. Mus., Bull., no. 215, p. 41, pl. 10, fig. 1.

Ticinella roberti (Gandolfi). – Sigal, 1952, XIX Congr. Géol. Internat., sér. 1, Algérie, no. 26, p. 24, text-fig. 19. – Ayala, 1954, Asoc. Mex. Geol. Petrol., Bol., vol. 6, no. 11–12, p. 426, pl. 16, fig. 1. – Banner and Blow, 1959, Palaeontology, vol. 2, pt. 1, p. 8, pl. 3, fig. 3.

Test free, in a low trochospiral coil of about two and one-half volutions, spiral side gently convex, opposite side with broad umbilicus, periphery broadly rounded, peripheral outline lobulate; chambers increasing gradually in size as added, about seven to eight in the final whorl, early chambers with somewhat rugose surface; sutures distinct, depressed, nearly radial but gently curved on the spiral side, straight and radial on the umbilical side; wall calcareous, finely perforate, without a keeled margin; primary aperture a low, interiomarginal, extraumbilical-umbilical arch, low secondary sutural apertures near the umbilical margin, opening into the chambers, and bordered by a narrow lip.

Figured hypotype is 0.33 mm. in diameter, 0.14 mm. in thickness. The holotype was approximately 0.5 mm. in diameter.

Remarks: Somewhat similar in appearance to *Hedbergella trocoidea*, the present species differs in having secondary sutural apertures. It differs from *Ticinella multiloculata* (Morrow) in having a narrower umbilicus and less prominent supplementary apertures, which are not as nearly umbilical in position. According to Sigal (1952, p. 23), *Ticinella roberti* is characteristic of the mid-

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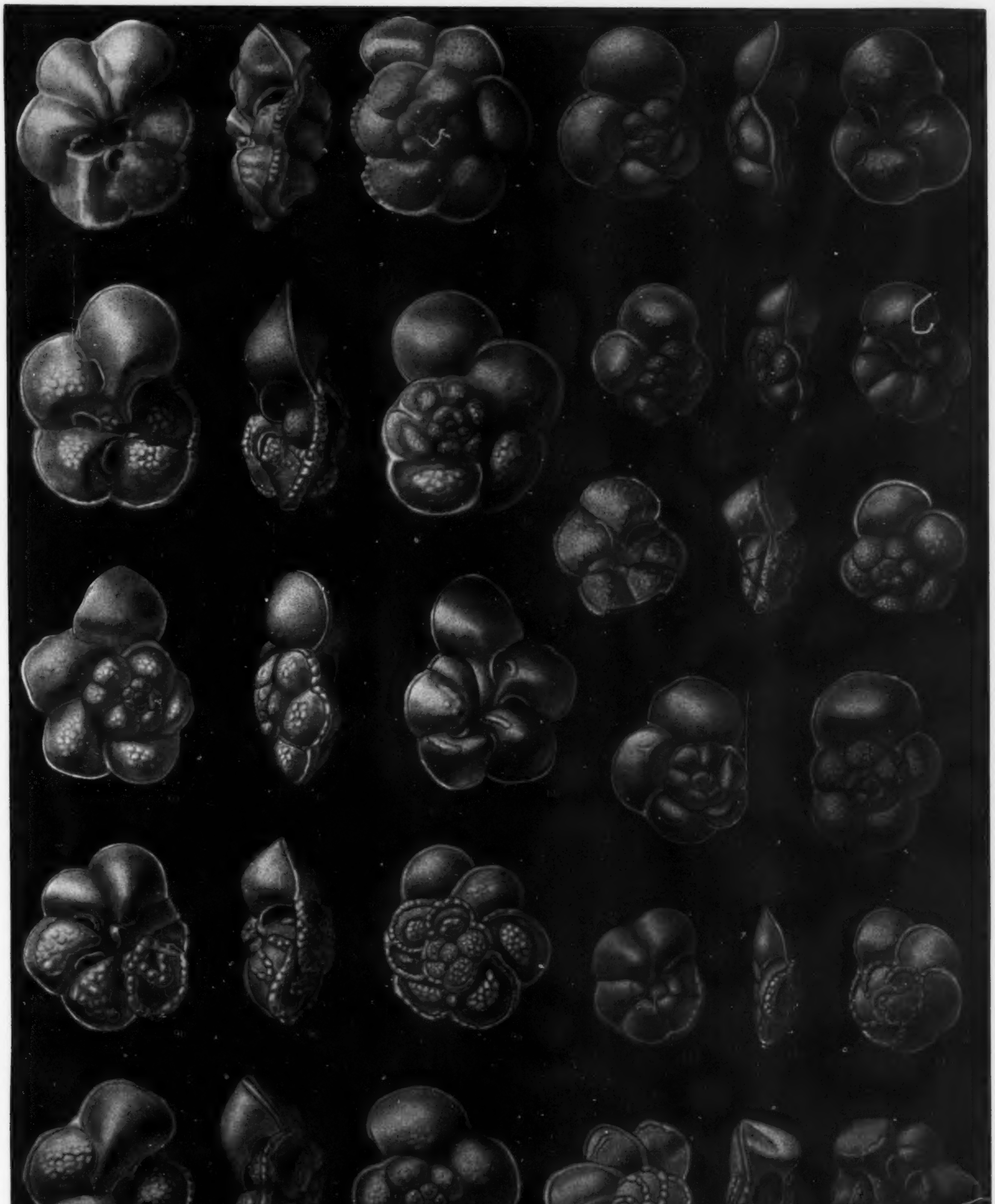
PLATE 8

Figures 11, 12 × 45, all others × 60

1–10 *Rotalipora cushmani* (Morrow)
1a–c, topotype of *R. turonica* Brotzen (USNM P 50) from the Turonian of Pommerania. 2a–3c, 6a–7, 9a–c, topotypes of *R. cushmani*, to show range of variation, from the Greenhorn limestone (Hartland shale member) of Kansas. 4a–c, 8, 10a–c, hypotypes from the subsurface Atkinson formation of Georgia. 5a–c, hypotype from the Cenomanian of California.

11 *Rotalipora balernaensis* Gandolfi
11a–c, topotype from the Cenomanian of Switzerland.

12 *Rotalipora reicheli* Mornod
12a–c, hypotype from the Cenomanian of Germany.



Albian. However, the original occurrence was from the lower Cenomanian, bed 27 at Breggia, and it seems probable that the strata in Algeria and those in Switzerland are equivalent in age, as this species apparently does not have a wide range. The assigned age of these strata in Switzerland has also varied, as it was considered upper Albian by Reichel (1947) and as lower Cenomanian by Reichel (1958). Banner and Blow (1959, pl. 3, fig. 3) refer to this species a specimen from the upper Albian or lower Cenomanian of Tanganyika.

Types and occurrence: Figured topotype (USNM P 4829) from bed 27, lower Cenomanian, "Scaglia bianca," Breggia River, near Chiasso, Canton Ticino, Switzerland.

Genus Rotalipora Brotzen, 1942

Rotalipora BROTZEN, 1942, Sver. Geol. Unders., Avh., Ser. C, no. 451, (Årsbok 36, no. 8), p. 32.

Type species: Rotalipora turonica Brotzen, 1942 = *R. cushmani* (Morrow), 1934. Fixed by original designation and monotypy.

Test free, trochospiral, biconvex to planoconvex, umbilicate, periphery angular, with a single keel; chambers angular-rhomboid; sutures curved on spiral side, depressed to elevated, and may be thickened or beaded, on umbilical side radial to slightly curved, flush to depressed; wall calcareous, perforate, radial in structure, surface smooth to nodose; primary aperture interiomarginal and extraumbilical-umbilical in position, with a bordering lip, a single secondary sutural aperture per suture on the umbilical side, or rarely two or more per suture, commonly also with a bordering lip or thickened rim.

Remarks: In 1957, Bolli, Loeblich and Tappan included within this genus both the typical keeled species and the nonkeeled forms described as *Ticinella* by Reichel, 1950. We here recognize the latter as a distinct genus, characterized by the absence of a keel or poreless margin.

Rotalipora appenninica (O. Renz)
Plate 7, figures 11, 12

Globotruncana appenninica O. RENZ, 1936, Eclogae Geol. Helv., vol. 29, pp. 20, 135, text-figs. 2, 7a, pl. 6, figs 1–11; pl. 7, fig. 1; pl. 8, fig. 4. – GANDOLFI, 1942 (part), Riv. Ital. Pal., vol. 48, no. 4, p. 116, text-figs. 43–44, pl. 2, figs. 5–6; pl. 4, figs. B 13–14, figs. C 24–27, E 45–46; pl. 5, figs. 5, 6 (part); pl. 6, fig. 4 (part); pl. 9, figs. 3, 6–7; pl. 12, figs. 3, 6; pl. 14, figs. 3–4. – BOLLI, 1945, Eclogae Geol. Helv., vol. 37, no. 2, p. 223, text-fig. 1 (1–2), pl. 9, fig. 1.

Globotruncana apenninica O. Renz forma *typica* GANDOLFI, 1942, Riv. Ital. Pal., vol. 48, no. 4, p. 116, text-fig. 42 (nos. 2–3), pl. 2, figs. 5–6; pl. 4, fig. 13.

Globotruncana appenninica appenninica O. Renz. – CITA, 1948, Riv. Ital. Pal. Strat., ann. 54, fasc. 3, p. 1, pl. 3, fig. 1.

Globotruncana (Rotalipora) apenninica O. Renz var. *typica* Gandolfi. – MORNOD, 1950, Eclogae Geol. Helv., vol. 42, no. 2, p. 582, text-fig. 9 (no. 2).

Globotruncana (Rotalipora) apenninica O. Renz. – REICHEL, 1950, Eclogae Geol. Helv., vol. 42, no. 2, p. 604, pl. 16, fig. 4; pl. 17, fig. 4; text-fig. 4. – MORNOD, 1950, Eclogae Geol. Helv., vol. 42, no. 2, p. 578, text-figs. 3–4 (III, IV), 5 (I), pl. 15, fig. 1a–1.

Globotruncana apenninica cf. α Gandolfi. – BOLLI, 1951, Jour. Pal., vol. 25, no. 2, p. 193, pl. 34, fig. 1.

Rotalipora apenninica (O. Renz). – SIGAL, 1952, XIX Cong. Géol. Internat., Monog. Reg., sér. 1, Algérie, no. 26, p. 24, text-fig. 23.

Rotalipora appenninica (O. Renz). – SUBBOTINA, 1953 (part), Trudy Vses. Neft. Naukno-Issledov. Geol.-Razved. Inst., n. ser., vol. 76, p. 159, pl. 1, figs. 5–6 (not figs. 7–8); pl. 2, figs. 1–2. – AYALA, 1954, Asoc. Mex. Geol. Petrol., Bol., vol. 6, no. 11–12, p. 416, pl. 13, fig. 1. – HAGN AND ZEIL, 1954, Eclogae Geol. Helv., vol. 47, no. 1, p. 22, pl. 1, fig. 1; pl. 4, figs. 11–12; pl. 5, fig. 1. – BOLLI, 1957, U. S. Nat. Mus., Bull., no. 215, p. 54. – BYKOVA, VASILENKO, VOLOSHINOVA, MIATLIUK AND SUBBOTINA, 1959, Osnovy Paleontologii, text-fig. 683.

Rotalipora appenninica (O. Renz) var. *typica* (Gandolfi). – AYALA, 1954, Asoc. Mex. Geol. Petrol., Bol., vol. 6, no. 11–12, p. 418, pl. 12, fig. 3.

Globotruncana (Rotalipora) apenninica apenninica O. Renz. – GANDOLFI, 1957, Cushman Found. Foram. Res., Contr., vol. 8, pt. 2, p. 60, pl. 9, fig. 1.

Not *Rotalipora* cf. *R. appenninica* (O. Renz). – BOLLI, LOEBLICH AND TAPPAN, 1957, U. S. Nat. Mus., Bull., no. 215, p. 41, pl. 9, fig. 5.

Test free, large, trochospiral, biconvex, periphery acutely angled and keeled, peripheral outline lobulate; all chambers of the approximately two whorls visible on the spiral side, chambers broad and low, flattened and lunate in outline as seen from the spiral side, increasing gradually in size as added, although rarely a specimen may have the final chamber proportionately larger than normal, this character seemingly not consistent, and possibly a gerontic character or influenced by local conditions, final whorl with six or seven, rarely five chambers, only these being visible on the umbilical side, where they are inflated and angularrhomboid with pronounced umbilical shoulder, umbilicus small; sutures distinct, raised, thickened, curved and oblique on the spiral side, depressed, radial and straight to gently curved on the umbilical side; wall calcareous, finely perforate, surface smooth except for the elevated and thickened sutures and keel on the spiral side; primary aperture a low, interiomarginal, extraumbilical-umbilical arch, secondary sutural apertures consisting of a single relatively large but low arch with thickened rim along each suture and placed near the position of the umbilical shoulder of the chambers.

Hypotypes range from 0.19 to 0.92 mm. in diameter. Larger figured specimen is 0.75 mm. in diameter and 0.26 mm. in thickness.

Remarks: Originally described from thin sections, *Globotruncana appenninica* was later regarded (Gandolfi, 1942)

as having a number of varieties, four of which are now considered as distinct species. *Globotruncana apenninica* var. α Gandolfi was later described as the variety (now species) *balernaensis* Gandolfi; *G. apenninica* var. β became *Globotruncana stephani* var. *turbinata* Reichel (= *Praeglobotruncana stephani* (Reichel)), and *G. apenninica* var. γ was described as *Globotruncana* (*Rotalipora*) *reicheli* Mornod. The present species (*Rotalipora appenninica* s. s.) thus includes only the forma *typica* or s. s. of Gandolfi.

Gandolfi (1942) variously used the different terms "forma typica" (p. 119), "s. str." (pl. 2, figs. 5, 6) and "var. typ." (pl. 4, figs. B 13, 14). These were originally used by Gandolfi as synonymous terms, but were regarded as distinct varieties by later workers (Mornod, 1950; Ayala, 1954). If a subspecific name were to be used, the subspecies including the holotype of the species would necessarily be the same as the species itself (thus, *R. appenninica appenninica*) as it was cited by Cita (1948) and Gandolfi (1957). *Rotalipora appenninica* var. α Gandolfi of Bolli (1951) appears closer to typical *appenninica* than to *R. balernaensis*, to which Gandolfi's variety α is now referred.

Subbotina (1953, p. 147) recorded "flattened" *Rotalipora appenninica* (Renz) and *Rotundina stephani* (Gandolfi) from the upper Albian or lower Cenomanian, stating that the upper Cenomanian species, *Rotalipora reicheli* (Mornod) and *Rotundina marginata* (Reuss) were more inflated. The original types of *R. appenninica* were relatively angular, however, and were from the upper Cenomanian. The specimens figured by Subbotina (pl. 1, figs. 7–8) probably should be referred to *R. greenhornensis* (Morrow).

The lower Cenomanian form referred to *Rotalipora* cf. *R. appenninica* O. Renz by Bolli, Loeblich and Tappan (1957, pl. 9, fig. 5) is also now regarded as *Rotalipora evoluta* Sigal. The latter is probably ancestral to *R. appenninica*, being smaller in size, less angular in appearance and with a more rapid increase in chamber size and less oblique sutures on the spiral side.

Types and occurrence: Figured (figs. 11–12) and unfigured hypotypes from the Maness formation in cores at 3600–3618, 3618–3635 and 3635–3665 feet in Shell Oil Company, S. T. Stephens No. 1, La Rue area, Henderson County, Texas. Unfigured hypotypes from the Cenomanian, Breggia Number 50, Canton Ticino, Switzerland.

Rotalipora balernaensis Gandolfi
Plate 8, figure 11

Globotruncana (Rotalipora) apenninica subsp. *balernaensis* GANDOLFI, 1957, Cushman Found. Foram. Res., Contr., vol. 8, pt. 2, p. 60, pl. 8, fig. 3.

Globotruncana apenninica O. Renz var. α GANDOLFI, 1942, Riv. Ital. Pal., ann. 48, mem. 4, p. 119, text-fig. 40, pl. 4, fig. B12; pl. 9, fig. 4; pl. 14, fig. 1.

Globotruncana (Rotalipora) apenninica O. Renz var. *alpha* Gandolfi. – REICHEL, 1950, Eclogae Geol. Helv., vol. 42, no. 2, p. 605, text-fig. 3.

Test free, large, low trochospiral coil of nearly three volutions, periphery angular and keeled, peripheral outline moderately lobulate; chambers flattened on the gently convex spiral side, increasing gradually in size as added, and of slightly greater breadth than height, wedge-shaped in outline on the umbilical side and inflated near the mid-portion of the chambers, about six chambers in the final whorl, rarely as many as eight, surrounding the large and deep umbilicus; sutures distinct, curved and oblique, raised and thickened on the spiral side, straight, radial and depressed on the umbilical side; wall calcareous, finely perforate, surface smooth except for the raised spiral sutures and thickened keel; primary aperture an interiomarginal, extraumbilical-umbilical arch, with a narrow bordering lip, secondary sutural apertures with narrow thickened rims on the umbilical side and closely adjacent to the umbilical area.

Topotypes range from 0.31 to 0.41 mm. in diameter. Figured topotype is 0.37 mm. in diameter and 0.16 mm. in thickness.

Remarks: Described by Gandolfi as a variety of *Globotruncana* (*Rotalipora*) *apenninica*, this form is here regarded as a distinct species. It differs from *Rotalipora evoluta* in having a more gradual increase in chamber size and less obliquely curved sutures, and from *R. appenninica* in being less ornamented, in lacking keels and ornamentation on the umbilical side, and in the less rapid increase in chamber size.

Types and occurrence: Figured and unfigured topotypes from the lower Cenomanian, bed number 34, Breggia River, near Chiasso, Canton Ticino, Switzerland.

Rotalipora cushmani (Morrow)
Plate 8, figures 1–10

Globorotalia cushmani MORROW, 1934, Jour. Pal., vol. 8, p. 199, pl. 31, figs. 2, 4. – CUSHMAN, 1946, U. S. Geol. Survey, Prof. Paper, no. 206, p. 152, pl. 62, fig. 9. – GAUGER, 1953, in Peterson, Gauger and Lankford, Utah, Geol. Min. Survey, Bull. 47, p. 83, pl. 10, figs. 1–3. – FRIZZELL, 1954, Texas, Univ., Bur. Econ. Geol., Rept. Invest. 22, p. 129, pl. 20, fig. 28. – APPLIN, 1955, U. S. Geol. Survey, Prof. Paper, no. 264–I, p. 196, pl. 48, figs. 25–26.

Rotalipora cushmani (Morrow). – SIGAL, 1948, Rev. Inst. Franç. Pétr., vol. 3, no. 4, p. 96, pl. 1, fig. 2; pl. 2, fig. 1. – HAGN AND ZEIL, 1954, Eclogae Geol. Helv., vol. 47, no. 1, p. 29, pl. 1, fig. 3; pl. 4, figs. 8–10. – AYALA, 1954, Asoc. Mex., Geol. Petrol., Bol., vol. 6, no. 11–12, p. 418, pl. 16, fig. 2. – BRONNIMANN AND BROWN, 1956, Eclogae Geol. Helv., vol. 48, no. 2, p. 537, pl. 20, figs. 10–12. – ZIEGLER, 1957, Neues Jahrb. Geol. Pal., Monatsheft, vol. 5, p. 198.

Rotalipora turonica BROTZEN, 1942, Sver. Geol. Unders., Ser. C, no. 451, Års. 36, no. 8, p. 32, text-figs. 10, 11 (4). –

Sigal, 1948, Rev. Inst. Franç. Pétr., vol. 3, no. 4, p. 96, pl. 1, fig. 1. – Bermudez, 1952, Venezuela, Minist. Minas e Hidrocarb., Bol. Geol., vol. 2, no. 4, p. 100, pl. 18, fig. 6. – Hagn and Zeil, 1954, Eclogae Geol. Helv., vol. 47, no. 1, p. 27, pl. 1, fig. 5; pl. 4, figs. 3–4. – Ayala, 1954, Asoc. Mex. Geol. Petrol., Bol., vol. 6, no. 11–12, p. 422, pl. 14, fig. 2. – Bolli, Loeblich and Tappan, U. S. Nat. Mus., Bull., no. 215, p. 41, pl. 9, fig. 6.

Globotruncana (Rotalipora) montsalvensis Mornod, 1950, Eclogae Geol. Helv., vol. 42, no. 2, p. 584, text-figs. 4 (I), 7 (1, 2).

Globotruncana (Rotalipora) turonica Brotzen. – Reichel, 1950, Eclogae Geol. Helv., vol. 42, no. 2, p. 607, pl. 16, fig. 5; pl. 17, fig. 5.

Globotruncana (Rotalipora) cf. *G. (R.) turonica* Brotzen. – Edgell, 1957, Micropaleontology, vol. 3, no. 2, p. 109, pl. 1, figs. 16–18.

Test free, of medium size, in a low trochospiral coil, spiral side convex, with two to two and one-half whorls of chambers visible, early chambers subglobular and inflated, later ones of somewhat greater breadth than height, and marginally flattened toward the peripheral keel, umbilical side showing only the five to six, rarely seven inflated chambers of the final whorl around the deep umbilicus, the inflation being most prominent in a radial line extending from the umbilicus across the midportion of the chamber about half the distance to the periphery; sutures distinct and depressed, curved backwards at the periphery on the spiral side, radial on the umbilical side; wall calcareous, finely perforate, surface of later chambers smooth, that of earlier chambers may be spinose or rugose in appearance, peripheral keel narrow and finely nodose, visible adjacent to the spiral suture of earlier whorls on the spiral side; primary aperture a high interiomarginal, extraumbilical-umbilical arch, bordered by a distinctly projecting lip, a single sutural supplementary aperture present on each chamber, with the large and distinct openings extending from near the umbilicus about one-third to one-half the distance to the periphery, and opening into the chamber at the side opposite to that of the primary aperture, supplementary apertures bordered by a narrow lip.

Topotypes range from 0.37 to 0.70 mm. in diameter, and from 0.19 to 0.28 mm. in thickness.

Remarks: The similarity of the forms described as *Rotalipora cushmani* and *R. turonica* was noted by Reichel (1950, p. 605, footnote), but the former was regarded as having a somewhat flatter spire. As can be seen in the illustrated topotypes of *R. cushmani*, this character does not hold true and there is sufficient variation in the population to include typical *R. turonica*. As *Rotalipora cushmani* has priority, the name *turonica* is suppressed as a junior synonym. *Globotruncana* (*Rotalipora*) *montsalvensis* is also a junior synonym.

Under these various names, the species has been widely recorded, from the Greenhorn limestone of Kansas and South Dakota, Atkinson formation of Georgia, and from Utah and Texas. It has been found in the Cenomanian of Switzerland, in the upper Cenomanian—lower Turonian of the Aquitaine Basin of France, and in the same stratigraphic position in Germany, Algeria and Morocco and Australia. We also have this species in the Cenomanian of California. Possibly the lower Turonian references may actually be from the uppermost Cenomanian, but evidence for dating these as either Cenomanian or Turonian is not yet available.

Types and occurrence: Figured topotype of *Rotalipora cushmani* from the Greenhorn limestone (Hartland shale member), SE ¼ sec. 31, T. 21 S., R. 22 W., north bank of creek, about ¼ mile west of road, Hodgeman Co., Kansas. Collected by Max Furrer.

Figured hypotype (possibly topotype, from locality from which Brotzen's figured specimens were obtained) of "*Rotalipora turonica* Brotzen" (USNM P 50) from the lower Turonian of Gristow, Pommerania. Brotzen also recorded the species from the upper Cenomanian.

Figured and unfigured hypotypes from the Atkinson formation, core at 3690–3700 feet in Humble Oil and Refining Company, Bennett and Langsdale well No. 1, Echols Co., Georgia.

Unfigured hypotype from the Atkinson formation, Sun Oil Company, Barlow No. 1, core at 3719–3729 feet, Clinch Co., Georgia.

Figured hypotype from the Cenomanian, cen. sec. 32, T. 20 N., R. 5 W., Clark Valley, Fruto Quadrangle, Glenn Co., California, and unfigured hypotype from the Cenomanian, about 100 yards upstream from the above sample.

Rotalipora evoluta Sigal
Plate 7, figures 1–4

Rotalipora cushmani Morrow var. *evoluta* Sigal, 1948, Rev. Inst. Franç. Pétr., vol. 3, no. 4, p. 100, pl. 1, fig. 3, pl. 2, fig. 2. – Ayala, 1954, Asoc. Mex. Geol. Petrol., Bol., vol. 6, no. 11–12, p. 419, pl. 16, fig. 3.

Globorotalia delrioensis Plummer. – Tappan, 1940, Jour. Pal., vol. 14, no. 2, p. 123, pl. 19, fig. 14. – Loeblich and Tappan, 1946, Jour. Pal., vol. 20, no. 2, p. 257, text-fig. 4B.

Globorotalia almadenensis Cushman and Todd, 1948, Cushman Lab. Foram. Res., Contr. vol. 24, pt. 4, p. 98, pl. 16, fig. 24.

Globotruncana (Rotalipora) evoluta Sigal. – Reichel, 1950, Eclogae Geol. Helv., vol. 42, no. 2, p. 605 (footnote). – Küpper, 1955, Cushman Found. Foram. Res., Contr., vol. 6, pt. 3, p. 115, pl. 18, fig. 3a–c.

Globotruncana (Rotalipora) appenninica O. Renz var. *typica* Gandolfi. – Bolli, in Church, 1952, Cushman Found. Foram. Res., Contr., vol. 3, pt. 2, p. 69, text-fig. 2.

Globotruncana (Rotalipora) apenninica apenninica (Renz). – Küpper, 1955, Cushman Found. Foram. Res., Contr., v. 6, pt. 3, p. 114, pl. 18, fig. 2a–c.

Rotalipora cf. *R. appenninica* (O. Renz). – Bolli, Loeblich and Tappan, 1957, U. S. Nat. Mus., Bull., no. 215, p. 41, pl. 9, fig. 5.

Test free, small to medium in size, spiral side showing all of the one and one-half to two and one-half whorls of the low trochospiral coil, umbilical side with angular to keeled umbilical shoulder and small but deep umbilicus, periphery with a thickened keel which may be somewhat nodose in the early portion, but is smooth on the final chamber; usually five to six chambers or more rarely seven in the final whorl, the chambers angular rhomboid in shape, with lunate outline and flattened surface on the spiral side, broad and low in the early portion and becoming progressively higher in later portion with final chamber of proportionately greater height than those preceding, chambers wedge-shaped and angular on the umbilical side, with strongly angular to keeled umbilical shoulder; sutures distinct, raised and thickened, oblique and curved on the spiral side, straight, radial and depressed on the umbilical side; wall calcareous, distinctly perforate, but otherwise smooth except for the raised, thickened and nodose imperforate keel and sutures of the spiral side, but may be somewhat nodose in early chambers, in addition to the imperforate keel and nodose to keeled umbilical shoulder on the umbilical side; primary aperture a broad and high interiomarginal, extraumbilical-umbilical arch, in well-preserved specimens bordered with a distinct lip, a low, arched supplementary sutural aperture at the posterior margin of each chamber, on the umbilical side and situated near the angle of the umbilical shoulder, opening into the chamber just in front of the suture and bordered by a narrow lip or thickened rim.

Hypotypes range from 0.23 to 0.55 mm. in greatest diameter. Hypotype of figure 3 is 0.31 mm. in diameter, 0.15 mm. in thickness.

Remarks: Superficially this species resembles the more compressed specimens of *Praeglobotruncana delrioensis* (Plummer), but it differs in the greater degree of angularity of chambers, distinct umbilical shoulder and thickened keel and sutures, and in the presence of the supplementary sutural apertures on the umbilical side.

It differs from the later Cenomanian *R. appenninica* in being about one half as large, and in having more angular chambers and a more prominent umbilical shoulder. It occurs in Cenomanian strata in Texas, California, and in Algeria.

Examination of the holotype of *Globorotalia almadenensis* Cushman and Todd, confirms its placement by Küpper (1955, p. 115) in the synonymy of *Rotalipora evoluta*. The sutural secondary apertures are well shown in the holotype of *G. almadenensis*. Possibly the chambers are more angular than usual for this species because of some secondary compression.

Types and occurrence: Figured (fig. 2) and unfigured hypotypes from the Del Rio clay, on Shoal Creek, just south of the 34th Street bridge in Austin, Travis Co., Texas. Collected by H. T. and A. R. Loeblich. Hypotype of fig. 1 (USNM P 4873) was referred to *Rotalipora* cf. *R. appenninica* (Renz) by Bolli, Loeblich and Tappan, 1957, pl. 9, fig. 5, and is from the same locality.

Figured (figs. 3, 4) hypotypes from the Grayson formation, steep northwest-facing slope, $\frac{3}{4}$ mile due east of Burleson, 0.2 mile northeast of the old Burleson–Alvarado road, Johnson Co., Texas. Collected by H. T. and A. R. Loeblich.

Unfigured hypotypes from the Grayson formation, Grayson Bluff, on Denton Creek, $3\frac{1}{2}$ miles northeast of Roanoke, Denton Co., Texas. Collected by H. T. and A. R. Loeblich.

Rotalipora greenhornensis (Morrow)
Plate 7, figures 5–10

Globorotalia greenhornensis MORROW, 1934, Jour. Pal., vol. 8, p. 199, pl. 31, fig. 1.

Planulina greenhornensis (Morrow). – CUSHMAN, 1940, Cushman Lab. Foram. Res., Contr. vol. 16, pt. 2, p. 37, pl. 7, fig. 1, – CUSHMAN, 1946, U. S. Geol. Survey, Prof. Paper, no. 206, p. 159, pl. 65, fig. 3.

Rotalipora globotruncanoides SIGAL, 1948, Rev. Inst. Franç. Pétr., vol. 3, no. 4, p. 100, pl. 1, fig. 4; pl. 2, figs. 3–5. – SIGAL, 1952, XIX Cong. Geol. Internat., Mon. Reg., sér. 1, Algérie, no. 26, p. 26, text-fig. 24. – HAGN AND ZEIL, 1954, Eclogae Geol. Helv., vol. 47, no. 1, p. 23, pl. 4, fig. 7. – BANNER AND BLOW, 1959, Palaeontology, vol. 2, pt. 1, pl. 2, fig. 4.

Thalmanninella brotzeni SIGAL, 1948, Rev. Inst. Franç. Pétr., vol. 3, no. 4, p. 102, pl. 1, fig. 5; pl. 2, figs. 6, 7. – BERMUDEZ, 1952, Venezuela, Minist. Minas e Hidrocarburos, Bol. Geol., vol. 2, no. 4, p. 53, pl. 7, fig. 2; pl. 27, fig. 5. – SIGAL, 1952, XIX Congr. Géol. Internat., Mon. Reg., sér. 1, Algérie, p. 26, text-fig. 25. – AYALA, 1954, Asoc. Mex. Geol. Petrol., Bol., vol. 6, no. 11–12, p. 423, pl. 15, fig. 1. – BRONNIMANN AND BROWN, 1956, Eclogae Geol. Helv., vol. 48, no. 2, p. 533.

Globorotalia decorata CUSHMAN AND TODD, 1948, Cushman Lab. Foram. Res., Contr. vol. 24, pt. 4, p. 97, pl. 16, fig. 21.

Globotruncana (Thalmanninella) brotzeni Sigal. – MORNOD, 1949, Eclogae Geol. Helv., vol. 42, no. 2, p. 586, text-fig. 9 (1).

Rotalipora appenninica (Renz). – SUBBOTINA, 1953 (part), Trudy Vses. Neft. Naukno-Issledov. Geol.-Razved. Inst., new ser., vol. 76, p. 159, pl. 1, figs. 7–8 (not pl. 1, figs. 5–6; not pl. 2, figs. 1–2).

Globotruncana (Rotalipora) globotruncanoides Sigal. – KÜPPER, 1955, Cushman Found. Foram. Res., Contr., vol. 6, pt. 3, p. 113, pl. 18, fig. 1.

Globotruncana (Thalmanninella) sp., KÜPPER, 1955, Cushman Found. Foram. Res., Contr., vol. 6, pt. 3, p. 115, pl. 18, fig. 4a–c.

Globotruncana n. sp. indet., KÜPPER, 1956, Cushman Found. Foram. Res., Contr., vol. 7, pt. 2, p. 44, pl. 8, fig. 3a–c.

Thalmanninella greenhornensis (Morrow). – BRONNIMANN AND BROWN, 1956, Eclogae Geol. Helv., vol. 48, no. 2, p. 535, pl. 20, figs. 7–9.

Globotruncana (Rotalipora) apenninica globotruncanoides Sigal. – GANDOLFI, 1957, Cushman Foundation Foram. Res., Contr., vol. 8, pt. 2, p. 60, pl. 9, fig. 2.

Rotalipora brotzeni (Sigal). – BOLLI, LOEBLICH AND TAPPAN, 1957, U. S. Nat. Mus., Bull., no. 215, p. 41, pl. 9, fig. 7.

Test free, trochospiral, spiral side convex, opposite side deeply umbilicate, periphery sharply angled and keeled, peripheral outline lobulate; chambers forming approximately two whorls, the earlier portion being somewhat indistinct, generally six to seven chambers in the final whorl, rarely as many as nine, chambers flattened on the spiral side, of greater breadth than height, inflated on the umbilical side with a distinct umbilical shoulder, apertural face of final chamber truncated and slightly concave, sutures distinct, depressed, curved and oblique, the beaded and elevated anterior chamber margin merging with the peripheral keel, and giving the appearance of elevated sutures on both sides, although most prominently on the spiral side; wall calcareous, finely perforate, surface of later chambers smooth, that of earlier chambers somewhat roughened in appearance; primary aperture a relatively high interiomarginal extraumbilical-umbilical arch, with a narrow lip, sutural secondary apertures distinct and arched, with a narrow bordering lip, and located just beneath the angle formed by the umbilical shoulder.

Topotypes range from 0.36 to 0.54 mm. in diameter, and from 0.16 to 0.28 mm. in thickness.

Remarks: Originally described as a *Globorotalia*, this species was later placed in *Planulina*, as no note was made of the sutural secondary openings. These sutural openings were later noted on the holotype and figured by Bronnimann and Brown (1956). The present writers have confirmed their observations in studying the holotype and also note these distinctive apertures in numerous topotypes.

Bronnimann and Brown also noted the similarity of this form to *Thalmanninella brotzeni* Sigal, but lacking specimens of the latter to confirm this, did not place the latter in synonymy. Having compared topotypes of the two described species, we regard them as conspecific, and *Rotalipora greenhornensis* the valid name. *Thalmanninella brotzeni* Sigal was described from the middle Cenomanian of Sidi Aïssa, Algeria, and was said to differ from *Rotalipora globotruncanoides*, which occurred with it, in being smaller, and in having a more pronounced biconvexity. In view of their many similarities, we regard *T. brotzeni* and *R. globotruncanoides* as mere individual variants within a population and consider both names as junior synonyms of *Rotalipora greenhornensis*. Probably "*T. brotzeni*" consists of the more juvenile specimens, the more pronounced biconvexity also being characteristic of these younger specimens of many other species. At the time of the description of the Algerian material, the true generic character of *R. greenhornensis* was not known, but interestingly enough, not only do the specimens show identical characters, but they occur in very similar assemblages. In both Kansas and Algeria the associated species include *Rotalipora cushmani*, *R. multiloculata* and *Praeglobotruncana stephani*. *Globotruncana apenninica* Renz var. *typica* Gandolfi from the Cenomanian of Switzerland was stated by Mornod (1949) to include *Rotalipora globotruncanoides* Sigal as a junior synonym. We have compared specimens of *G. appenninica* var. *typica* from bed 50 of the "Scaglia rossa," at Torrente Breggia, to our topotypes of *Rotalipora greenhornensis*, and the Algerian specimens of *R. globotruncanoides* and regard *G. appenninica* as distinct.

Gandolfi (1957, p. 60) also stated that *Globotruncana* (*Rotalipora*) *globotruncanoides* Sigal is closely related to *R. appenninica* (Renz) and probably descended from it, inasmuch as *G. globotruncanoides* "appears late in the Turonian." However, the species of Sigal was described from the middle Cenomanian, where it occurs with *R. cushmani*, and in the lower Cenomanian is found with *R. cushmani* var. *evoluta*, *R. ticinensis* and *Globigerina washitensis*, according to Sigal.

The type level of *R. appenninica* is middle to upper Cenomanian and thus it may be younger than *R. globotruncanoides* at its type locality. However, *R. globotruncanoides* is a synonym of *Rotalipora greenhornensis* and therefore ranges at least into the upper Cenomanian. *Rotalipora greenhornensis* and *R. appenninica* may even be contemporaneous. We regard *Rotalipora appenninica* (including the var. *typica* of Gandolfi) as a distinct species from *R. greenhornensis*.

Globorotalia decorata Cushman and Todd was described from Californian strata then thought to be early Cretaceous in age, but here regarded as Cenomanian. Comparison of the holotypes of the two species, *Globorotalia greenhornensis* Morrow and *G. decorata* Cushman and Todd shows them to be conspecific, and the latter name a synonym. *Globotruncana* (*Thalmanninella*) sp. of Küpper, 1955, and *Globotruncana* n. sp. indet. Küpper, 1956, are also synonymous, as can be seen by an examination of the figured specimens. Küpper also noted the similarity of his single specimen of the latter form to *Globotruncana* (*Rotalipora*) *globotruncanoides* Sigal, but stated that "this relationship cannot be further substantiated until more and better material is available." *G. globotruncanoides* is also a synonym of the present species.

Bronnimann and Brown (1956) mentioned the similarity of *Globotruncana appenninica* var. α Gandolfi and *G.* (*Rotalipora*) *appenninica* var. *alpha* Gandolfi of Reichel to the present species but did not consider them synonymous. The variety *alpha* was designated by Gandolfi (1957) as the type of *Globotruncana* (*Rotalipora*) *appenninica balernaensis*. We regard this as a distinct species, *Rotalipora balernaensis*, after having compared topotypes of this form with topotypes of the "species" *greenhornensis* and *brotzeni*.

In addition to the previously recorded occurrences (under the various names listed above) in the Greenhorn limestone of Kansas, the Cenomanian of California, Algeria, Morocco, Switzerland, Bavaria and Russia, we also have found this species in the Cenomanian from the submarine cores on the Blake Plateau north of the Bahama Islands, and from Niedersächsen, Germany.

Types and occurrence: Figured (fig. 9) and unfigured topotypes from the Greenhorn limestone (Hartland shale member), SE¼ sec. 31, T. 21 S., R. 22 W., north bank of creek about ¼ mile west of road, Hodgeman Co., Kansas. Collected by Max Furrer.

Unfigured hypotype from the Greenhorn limestone (Hartland shale member) on county road, ¼ mile north of Highway 156, 5.2 miles west-southwest of Gray, Hodgeman Co., Kansas. Collected by Max Furrer.

Figured (fig. 7) and unfigured hypotypes from the Cenomanian, cen. sec. 32, T. 20 N., R. 5 W., Clark Valley, Fruto Quadrangle, Glenn Co., California.

Figured (fig. 8) and unfigured hypotypes from the Cenomanian *Inoceramus crippsi* and *Schloenbachia varians* zones, Ziegelei Zeltberg at Luneburg, southeast of Hamburg, Niedersächsen, Germany.

Figured and unfigured hypotypes from the Cenomanian, Lamont Geological Observatory Core A 167–25, on escarpment of Blake Plateau, lat. 28°52′ N., long. 76°47′ W., at the following depths in centimeters in a core length of 175 cm.: 10, 20–30, 30–40, 40–50 (fig. 6), 50–60, 70–80, 80–90, 90–100 (fig. 5), 120–130, 130–140, 140–150, 150–160, 160–170 and 170–175.

Figured (fig. 10) topotype (USNM P 3930) of *Thalmanninella brotzeni* Sigal from the middle Cenomanian, Sidi-Aïssa, Algeria.

Rotalipora reicheli (Mornod)
Plate 8, figure 12

Globotruncana (Rotalipora) reicheli Mornod, 1950, Eclogae Geol. Helv., vol. 42, no. 2, p. 583, fig. 5 (IV a–c), fig. 6 (Nos. 1–6), pl. 15, figs. 2a–p, 3–8. – Noth, 1951, Austria, Geol. Bundesanst., Jahrb., Sonderband, 3, p. 76, pl. 5, fig. 3a–b. – Carbonnier, 1952, Soc. Géol. France, Bull., ser. 6, vol. 2, p. 119, pl. 7, fig. 4a–b.

Globotruncana apenninica O. Renz var. γ Gandolfi, 1942, Riv. Ital. Pal., ann. 48, mem. 4, p. 119, text-figs. 41 (1a, b), 42 (1), 44 (3–4), pl. 6, fig. 6 (part); pl. 14, fig. 6.

Rotalipora reicheli Mornod. – Hagn and Zeil, 1954, Eclogae Geol. Helv., vol. 47 no. 1, p. 25, pl. 1, fig. 2; pl. 4, figs. 1–2; pl. 7, fig. 11. – Ayala, 1954, Asoc. Mex. Geol. Petrol., Bol., vol. 6, no. 11–12, p. 421, pl. 14, fig. 1. – Gandolfi, 1955, Bull. Amer. Pal., vol. 36, no. 155, p. 83. – Bykova, Vasilenko, Voloshinova, Miatliuk, and Subbotina, 1959, Osnovy Paleontologii, text-fig. 684.

Test free, large, low trochospiral coil of two to three whorls, spiral side slightly convex, umbilical side strongly inflated to subangular, periphery narrowly keeled, acutely angled in early stages, becoming right-angled in the later portion, peripheral outline lobulate; chambers numerous, six to seven, more rarely eight, occurring in the final whorl, angular-truncate chambers low and broad, with flattened surface and lunate outline as seen from the spiral side, wedge-shaped and strongly inflated to angular and truncate on umbilical side, with well-developed umbilical shoulder in the later portion of the test; sutures distinct, oblique and curved, thickened, raised and nodose on the spiral side, radial, straight to gently curved and depressed on the umbilical side; wall calcareous, surface finely perforate, ornamented by the nodose keel and thickened sutures, the angular to keeled umbilical shoulder, and strongly angular chambers; primary aperture a high interiomarginal, extraumbilical umbilical arch, bordered with a flangelike lip, secondary sutural apertures on the umbilical side, consisting of a single high-arched opening just within the angle of the umbilical shoulder at each suture, with a thickened imperforate rim.

Greatest diameter of figured hypotype 0.60 mm., thickness 0.28 mm. Hypotypes from Switzerland (Breggia) from 0.52 to 0.73 mm. in diameter and hypotypes from Germany range from 0.41 to 0.68 mm. in diameter.

Remarks: This species is characterized by the nodose and thickened sutures and the keel on the spiral side, and the strongly inflated to angular truncate chambers on the umbilical side.

Types and occurrence: Figured and unfigured hypotypes from the Cenomanian, *Inoceramus crippsi* zone, Ziegelei Zeltberg at Luneburg, southeast of Hamburg, Niedersächsen, Germany.

Unfigured hypotypes from the Cenomanian, number 57, Breggia, Canton Ticino, Switzerland.

ACKNOWLEDGMENTS

We are deeply indebted to many co-workers for aid in this study. The material from the submarine core on the Blake Plateau was made available by D. B. Ericson, Lamont Geological Observatory, Columbia University, Palisades, New York. H. Hiltermann, Amt für Bodenforschung, Hannover, Germany, was helpful in obtaining Cenomanian material from northern Germany. J. D. Bainton, Standard Oil Company of California, Western Operations, Inc., Bakersfield, California, supplied material from the Cenomanian of the Sacramento Valley, California, and M. Furrer, formerly with California Exploration Company, San Francisco, California, collected the Greenhorn limestone localities of Morrow. Other material used in the present study was collected by the writers, as noted in the locality discussions of the systematic descriptions.

We are grateful to the U. S. National Museum, Washington, D. C., for the loan of primary types of Morrow, Cushman and Todd, Fox, etc., for comparison with our material; to Mrs. Katherine V. W. Palmer, Director of the Paleontological Research Institution, Ithaca, New York, for the loan of the Cretaceous types of Plummer; and to Miss Myra Keen and Dr. J. J. Graham, Stanford University, California, for permission to restudy the California Cretaceous planktonic types of Küpper at that institution. This paper was partially supported by funds from the California Research Corporation.

The illustrations are shaded camera lucida drawings prepared by L. B. Isham, Washington, D. C.

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ABSTRACT

A reinterpretation of the morphology of Nannoceratopsis *Deflandre 1938 is based on a study of many specimens of* N. deflandrei *Evitt n. sp. from the Lower Jurassic (Lias δ) of Denmark – the first dinoflagellate to be described from the Lower Jurassic.* Nannoceratopsis *is morphologically similar to Recent Dinophysiales, a group of dinoflagellates without a previously reported fossil record. The extreme infraspecific variability of the new species is analysed. Discovery of* N. pellucida *Deflandre, the type species, in the Upper Jurassic of Utah provides the first record of the genus in North America.*

The dinoflagellate Nannoceratopsis Deflandre: morphology, affinities and infraspecific variability

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INTRODUCTION

Excluding parasitic forms and a few other highly specialized types, the living dinoflagellates may be grouped into two major morphological categories; the Peridiniales-Gymnodiniales and the Dinophysiales. The Peridiniales-Gymnodiniales have an extensive fossil record that dates from the Jurassic, but the Dinophysiales have never been reported as fossils.

In the Perididiniales-Gymnodiniales the cell is usually globose or dorso-ventrally flattened. A rigid external theca composed of polygonal plates characterizes the Peridiniales (typical example: *Gonyaulax polyedra*, text-fig. 1); such a theca is absent in the Gymnodiniales. The transverse flagellum in these groups tends to be equatorial or subequatorial in position; in a few genera it is subapical. Lateral flattening in combination with a subapical girdle is unknown except in forms that are considered close to the stock that also gave rise to the Dinophysiales. Division of the theca in the Peridiniales takes place along the girdle or along a line crossing the girdle obliquely.

In the Dinophysiales (text-figs. 4, 6, 7) the cell tends to be laterally flattened and to have a transverse flagellum at the apical extremity, which may be extended beyond the main portion of the cell mass (text-fig. 4). Binary fission takes place along a sagittal line, dividing the old theca into two symmetrical halves. The surface along which the divisional suture runs is sometimes a band-like zone distinguishable from the lateral surfaces of the theca (text-fig. 7).

Dinoflagellates with morphology intermediate between these two types occur, principally in the genera *Amphidinium* (text-fig. 2) and *Thecadinium* (text-fig. 3). The former is the genus considered to approximate most closely the form ancestral to both groups, but it is assigned to the Peridiniales because it lacks a sagittal suture. *Thecadinium*, which divides along a sagittal line, is considered the most primitive genus of the Dinophysiales (Schiller, 1933, 1937).

Nannoceratopsis is a genus of morphologically unique dinoflagellates, first described from the Jurassic of France by Deflandre in 1938, and based on a single species, *N. pellucida*. Since then the only other published accounts of the genus are those by Cookson and Eisenack (1959, 1960), who refer specimens from the Jurassic of Oceania to the type species. In the present paper the type species is reported from the Upper Jurassic of Utah and a new species, *N. deflandrei*, is described from specimens in well cores of the Lower Jurassic (Lias δ) of Denmark. The Utah occurrence is the first record of the genus in North America. The new species from Denmark extends downward the known range of the genus from the Upper Jurassic to the upper Lower Jurassic. At the same time, the new species becomes the oldest described fossil dinoflagellate (although a still older one from the same area will be described shortly). Many species of Middle and Upper Jurassic dinoflagellates have been described by Deflandre (1938*b*, 1942, 1947), Downie (1957), Eisenack (1935, 1936*a*, 1936*b*), Valensi (1953), and Klement (1960).

Nannoceratopsis, as reinterpreted in this paper on the basis of *N. deflandrei* n. sp., has several distinctive morphological features (text-fig. 5) that suggest possible affinity with the Dinophysiales. These include marked lateral flattening of the cell, an apically located transverse flagellum, and a prominent sagittal band that separates the two large lateral surfaces of the theca. However, the diagnostic feature of the Dinophysiales – a sagittal divisional suture – has not been observed with certainty, although it is suggested by some specimens. As in the "primitive," "stock," or "transitional" genera, *Amphidinium* and *Thecadinium*, the theca in *Nannoceratopsis* was flexible, rather than rigid, and there is no indication of division into plates as in typical thecate Peridiniales.

Nannoceratopsis deflandrei n. sp., apparently in contrast to the type species, *N. pellucida*, shows a high infraspecific variability, exceeding that described for any other fossil dinoflagellate known to me. The observed variations are enumerated and discussed following the description of the new species.

The example of *N. deflandrei* indicates that fossil dinoflagellate species may be just as variable as Recent ones, as in *Ceratium* (Hasle and Nordli, 1951; Graham and Bronikowsky, 1944), *Ceratocorys* (Graham, 1942), numerous genera of the Dinophysoidae (Kofoid and Skogsberg, 1928), and others. Of course, variability can be fully ascertained only from an "adequate" sample. In turn, the size of an "adequate" sample will vary, since the variability itself will differ from species to species. In slightly variable species a few specimens may suffice; in highly variable species many will be needed. Unfortunately, descriptions of fossil dinoflagellates can seldom be based on as many specimens as were available for the study of *N. deflandrei*. However, some knowledge of infraspecific variability is important in the recognition and re-recognition of fossil species. If a species is based on a few specimens only, we simply must recognize that the variability is an unknown factor and will remain uncertain until many more specimens have been observed. Before one can properly evaluate and use a specific description, one must know the size of the population sample on which the description was based and the range of the observed variability within that sample. Only then can one analyze subsequent finds of the same or similar species intelligently, make accurate emendations of specific descriptions, or useful comparisons with other taxa. Accordingly, authors should be careful to indicate at least the approximate number of specimens on which their descriptions are based, and to specify (and, preferably, illustrate) the range of observed variation. The recent work of Klement (1960) is an excellent example of the careful description and illustration of variability within species of Jurassic dinoflagellates and hystrichospheres (although I disagree with his taxonomic treatment of cases such as *Gonyaulax cladophora* Deflandre, in which he designates as named subspecies the segments of an extensive range of variation displayed by specimens from a single rock sample).

TECHNIQUES AND COORDINATE NOTATION

The usual techniques for recovering acid-insoluble microfossils, as modified by the techniques described by Funkhouser and Evitt (1959), were used in preparing the samples. Photographs were taken with a Zeiss Photomikroskop, using both bright field and phase contrast illumination.

Specimens were embedded in a smear of a water-soluble mounting medium (polyvinyl alcohol or Clearcol) against the cover glass, which was mounted, in turn, with a xylene-soluble medium (Canada balsam or Permount). Locations of all figured specimens are shown by coordinates with reference to an index circle engraved near the lower left corner of the cover glass and marked in ink with an "X." For example, the notation R 30.4, +5.6 indicates that the specimen lies 30.4 mm. to the right (L is used for left) and 5.6 mm. toward the upper edge (– is used for lower edge) of the slide from the index circle. The individual specimens are also within circles engraved on the cover glass.

ACKNOWLEDGMENTS

I take pleasure in thanking Professor Georges Deflandre for the opportunity to examine the type material of *N. pellucida*. Permission to publish this paper has been granted by the Jersey Production Research Company.

SYSTEMATIC DESCRIPTIONS

DINOFLAGELLATA
?DINOPHYSIALES

Genus **Nannoceratopsis** Deflandre, 1938, **emended**

Nannoceratopsis (as *Nannoceratopsis pellucida*) DEFLANDRE, 1938 Acad. Sci. Paris, C. R., vol. 206, p. 688, text-fig. 5 Nomen nudum.

Nannoceratopsis DEFLANDRE, 1938, Stat. Zool. Wimereux, Trav., vol. 13, p. 183.

Type species: N. pellucida Deflandre, 1938; Upper Jurassic (Oxfordian), Villers-sur-Mer, France.

Diagnosis: Theca laterally compressed, usually subtriangular with two prominent antapical horns (points) separated by antapical concavity. Ventral antapical horn may be reduced or completely undeveloped, causing thecal outline to be ovoid in extreme cases. Epitheca minute, separated by subapical girdle from the hypotheca that constitutes most of the theca. Dorsal, antapical, and ventral surfaces of hypotheca narrow, set off from larger lateral surfaces by narrow ridges developed with variable distinctness. Longitudinal furrow confined to the hypotheca where it occupies a portion of narrow ventral surface.

Corpus compressum ex lateribus, saepe subtriangulum cum duobus cornibus (cuspidibus) prominentibus positis contra apicem et separatis cavo. Cornu ventralis redigatur aut admodum absens, faciens formam corporis ovatam in exemplis insolitis. Epitheca minima, separata ab hypotheca cingulo posito ad

apicem, itaque hypotheca facit partem maiorem thecae. Superficies et dorsalis et antapicalis et ventralis hypothecae angustae, dividae ab superficibus lateralibus costis angustis variantis visu. Sulcus finitus hypothecae ubi occupat partem superficiei angustae ventralis. Abruptio imperfecta per cingulum.

Remarks on generic characters: The transverse furrow begins at the apical limit of the longitudinal furrow, into which it merges obliquely. It then encircles the apical prominence, ending at a ridge that joins the small apical surface with the left edge of the longitudinal furrow. A thin flaplike structure begins low on this ridge and flares upward and outward along the righthand edge of the apical surface, i.e., the apical edge of the girdle. This flexible structure, which is variably distorted and folded, forms an extended "roof" to the girdle on the right side. It is almost semicircular in plan view, thickens at its base to merge imperceptibly with the apical surface proper, and does not extend to the dorsal midline. On the left side, the apical edge of the girdle is irregularly thickened. The thin theca is frequently torn at the girdle, especially on the dorsal, side so that the epitheca is often displaced or lacking. The limits of the longitudinal furrow may be obscure, or conspicuous ridges may set it off from the bounding areas. As a result of variation in the conspicuousness of the ridges at the antapical limit of the longitudinal furrow, the ventral outline of the theca in side view may be an unbroken curve or interrupted by an obtuse angle.

Discussion: Deflandre drew attention to the characteristic apical structure of *Nannoceratopsis.* He interpreted the oblique groove (clearly illustrated in the type species) as the longitudinal furrow and the surface bearing it as ventral. However, the phraseology of his description indicates that this furrow did not appear to him to be a conventional longitudinal furrow. He indicated that the oblique furrow might possibly be interpreted as the girdle and stated (p. 183) that the "apex de structure particulière ... ne peut être étudié que dans des conditions très favorables."

On the basis of the abundant well-preserved material of *N. deflandrei* n. sp., it is now possible to offer a more detailed interpretation of the apical structure and to confirm that the furrow observed by Deflandre is a part of a subapical girdle. The true longitudinal furrow is identified in another position where it has a more conventional apical-antapical alignment.

This revised interpretation has two effects. One is to change the orientation; the major flattened surfaces, which were dorsal and ventral in accord with Deflandre's analysis, are now seen to be lateral. This means that the conspicuous antapical points (in *N. deflandrei*, horns in *N. pellucida*) are dorsal and ventral, rather than right and left. A second effect is to provide additional evidence on the affinities of the genus as discussed below.

Deflandre described *Nannoceratopsis* as "un microorganisme dont l'aspect immédiate est très caractéristique" (1938, p. 183). This statement is still true. The apical structure, the triangular outline with two antapical horns, and the thin, colorless wall remain the diagnostic features. However, the revised interpretation makes *Nannoceratopsis* truly unique among fossil dinoflagellates. No other fossil forms with pronounced lateral flattening or with a subapical girdle have been recorded.

Affinities: Deflandre (1938*b*) first drew attention to the possible dinophysalean affinities of *Nannoceratopsis* when he noted certain similarities to the living genera *Amphidinium, Thecadinium* and *Triposolenia* (text-figs. 2–4). These are particularly apparent if the apical furrow is interpreted as the girdle. The additional morphological details revealed by *N. deflandrei* suggest the same comparisons, as well as certain resemblances to another Recent genus, *Dinophysis* (text-figs. 6, 7). These similarities are summarized below.

	N. deflandrei	*Thecadinium*	*Dinophysis*	*Triposolenia*	*Amphidinium*
Lateral flattening	X	X	0–moderate	X	some spp.
Subapical girdle	X	X	X	X	X
Sagittal band	X	X	some species	0	0
Sagittal division	unobserved	X	X	unobserved	0
Wall	flexible	flexible	rigid	rigid	flexible
Antapical projections	broad e. c. c.	0	spines or broad e. c. c.	long, slender e. c. c.	0

X – feature present; 0 – none, feature not present;
e. c. c. – extensions of cell cavity

One of the more striking features of *Nannoceratopsis* is the sagittal band that separates the two flattened lateral surfaces (text-fig. 5b). A similar band (text-fig. 7) is developed in many typical Dinophysiales (Schiller, 1933). It also occurs in the less typical *Thecadinium* (Lebour, 1925), but not in *Amphidinium.* In the Dinophysiales the suture along which division takes place runs along the middle of this band. This suture is suggested in some specimens of *N. deflandrei* but cannot be clearly demonstrated. In *Thecadinium* the separation of the theca along a sagittal line apparently has been observed only in specimens treated with "suitable reagents" (Lebour, 1925); it is not developed in *Amphidinium.*

Certainly, as Deflandre pointed out, *Nannoceratopsis* is not closely comparable with any modern form. The more important similarities seem to me to be with the Dinophysiales, rather than with the Peridiniales-Gymnodiniales. However, three considerations urge caution in assignment to the Dinophysiales:

1) The existence of a sagittal divisional suture in *Nannoceratopsis* has not been demonstrated.

2) The Dinophysiales have no other known fossil representatives, whereas *Nannoceratopsis* is known only from the Jurassic. The intervening gap, representing almost the entire known evolutionary history of the dinoflagellates, is as yet devoid of known forms that would tie the two more firmly together.

3) In *Amphidinium* and *Thecadinium* the combination of flexible theca, lateral flattening and subapical transverse flagellum is associated with an ecological adaptation unusual for dinoflagellates; a life in and on the sand beneath shallow waters (Lebour, 1925). It is conceivable that *Nannoceratopsis* may represent a similar specialization in a group only very remotely related to the other two.

In view of all these considerations, *Nannoceratopsis* is referred here, with query, to the Dinophysiales.

Nannoceratopsis deflandrei Evitt, **new species**

Plate 1, figures 1–14; Plate 2, figures 1–29; text-figures 5, 9–17

Diagnosis: Outline shape highly variable. Most specimens subtriangular with two antipical horns as short, broad points separated by gentle concavity; ventral point shorter than dorsal. Outline varies to ovoid as ventral point varies from prominent to completely absent; ventral point (rarely dorsal one) may be rounded. Sagittal band relatively wide. Ridges bounding lateral surfaces and crossing sagittal band (especially at end of longitudinal furrow) commonly prominent. Mean size of subtriangular individuals: 73μ by 60μ in lateral view.

Forma corporis magne varia. Plurima exempla subtriangula cum duobus cornibus positis contra apicem et apparentis ut cuspides et lati et breves separatis cavo leve; cuspis ventralis brevior. Forma corporis fit ovatum dum cuspis ventralis variat ab conspicuo ad absentem. Vinculum sagittale fere latum. Costae circum superficies laterales et transientes vinculum sagittale (praesertim in fine sulci) saepe prominentes. Magnitudo media individuorum subtriangulorum 73μ × 60μ visorum ab latere.

Material and occurrence: Several hundred specimens were studied out of several thousand in the prepared slides. All came from a core sample of dark gray, non-calcareous shale taken at a depth of 3967 feet in the Danish American Prospecting Company's Gassum No. 1 well, 10 km. north of Randers, Jutland, Denmark; geographic coordinates: 56°34′ N. Lat., 10°02′ E. Long. Stratigraphic position of sample: Lower Jurassic, Pliensbachian (Lias δ, zone of *Pleuroceras spinatum* and *Amaltheus margaritatus*). Top of Lias δ is at about 3910 feet and the zone extends to about 4285 feet.

Although *N. deflandrei* is prolific at 3967 feet, it is the only dinoflagellate in the sample. Associated acid-insoluble microfossils include a rich assortment of gymnospermous pollen (disaccate and cycadaceous), a moderately varied assemblage of trilete spores, several small species of simple hystrichospheres, and occasional specimens of *Tytthodiscus* sp.

This occurrence extends downward the known range of *Nannoceratopsis* and means that *N. deflandrei* is the oldest dinoflagellate yet described. However, a still older one (to be the subject of a future paper) is a typical tabulate Peridiniales from the Hettangian (Lias α, zone of *Schlotheimia angulata*), also from the DAPCO Gassum No. 1 well, about 735 feet below the horizon of *N. deflandrei* noted above.

Types: Holotype and figured paratypes are in the U.S. National Museum. Holotype USNM 139385; R 30.4, +5.6 (pl. 1, fig. 13), a specimen with both antapical points well developed. Figured paratypes: 49 specimens (pl. 1, figs. 1–12, 14; pl. 2, figs. 1–29; text-figs. 9–17); USNM numbers and coordinates tabulated in plate and figure explanations.

Description: Because of the marked original flattening, almost all specimens are seen in lateral view; this is the view to be understood unless otherwise specified.

Theca laterally compressed, typically subtriangular with acute apex and two antapical points (dorsal and ventral). Dorsal and ventral outlines convex, antapical outline concave. Epitheca minute, separated by subapical girdle from much larger hypotheca. Epitheca more or less flattened apically in plane about at right angles to lateral thecal surfaces; typically marked in center by small conical prominence; extended on right-hand side into somewhat undulated flap that projects over girdle; on left side thickened along edge of girdle. No apical pore observed.

Girdle usually well developed, least clearly set off from adjoining hypotheca on left side; right end oblique, merged with longitudinal furrow; dorsal portion horizontal; left portion horizontal to slightly oblique. Flagellar pore occasionally visible (pl. 1, figs. 10, 14), relatively large, in longitudinal furrow at junction with girdle.

Hypotheca composed of three principal parts: two large, relatively flat lateral surfaces separated by low ridges from narrow sagittal band between them. Sagittal band commonly divided into dorsal, antapical and ventral portions by transverse ridges at dorsal and ventral antapical points. Longitudinal furrow occupies portion of band on ventral surface; ridges marking lateral and antapical limits of longitudinal furrow often broader and more distinct than others.

Dorsal outline of hypotheca gently convex from girdle to dorsal antapical point. Ventral outline commonly interrupted by obtuse angle at antapical end of longitudinal furrow. Outline highly variable between dorsal antapical point and antapical end of longitudinal furrow. Ventral antapical point distinctly developed in about 60 per cent of individuals (triangular types), barely or not at all distinguishable in 25 per cent

(oval types), distinct but reduced in 15 per cent (intermediate types). Outline between antapical points usually moderately concave, rarely deeply so and rarely straight to slightly convex (see discussion of variations and pl. 2, figs. 1–29). Antapical points acute or rounded; sagittal band typically crossed at each point by crestlike ridge that appears as spinelike structure in two-dimensional lateral view.

Hypotheca and epitheca joined by narrow ridge between left margin of longitudinal furrow and ventral edge of epithecal surface. Tapered and undulated antapical extremity of flap that expands over right hand portion of girdle lies along this ridge. Wall thin, finely areolate (pl. 1, fig. 2) except for smooth girdle.

Size: Forms with two antapical points clearly developed (based on 100 specimens): length 55–90μ (mean 73μ), width 45–70μ (mean 60μ). Forms with one antapical point only (based on 25 specimens) length 50–75μ, width 40–55μ. In many of the larger specimens the sagittal band is about 7μ wide.

The following discussion of infraspecific variability is an important part of the specific characterization.

Infraspecific variability: The striking infraspecific variability of *N. deflandrei* is best considered under four headings:

1) Variability and pseudovariability of apical structures.

2) Variability in outline shape and in size.

3) Variability in surface structures of hypotheca.

4) Variability in appearance of wall.

1) Variability and pseudovariability of apical structures.
The features described here as apical structures include the girdle and the small epitheca. At first glance these features appear to be highly variable. However, this is actually a misleading pseudovariability that results chiefly from differences in the degree and direction of flattening of the delicate three-dimensional structures in the apical region. Careful comparison of the apical structures in many specimens shows them to be relatively much less variable than either the outline shape or the surface features of the hypotheca.

The principal pseudovariable is the flap that extends from the apical edge of the girdle on the right side. This structure is large compared to the other apical structures. As shown by the illustrations the manner in which it is distorted by compression has a great influence on the appearance of the apex. However, when allowance is made for differences in compression, the flap is seen to be relatively constant in shape, size and position. The same is true of the thickening along the apical edge of the girdle on the left side. In some specimens the whole apical end is displaced or entirely missing. This, too, seems possibly to result from accidental rupture along the thin wall of the girdle, rather than from separation along a preformed line (associated with reproduction or the escape of protoplasm) as has been noted in other fossil dinoflagellates.

The chief true variable in the apical region is less conspicuous. This is the generally transverse surface of the epitheca itself. It may be relatively flat or concial, commonly bearing a small but conspicuous central prominence, also usually conical.

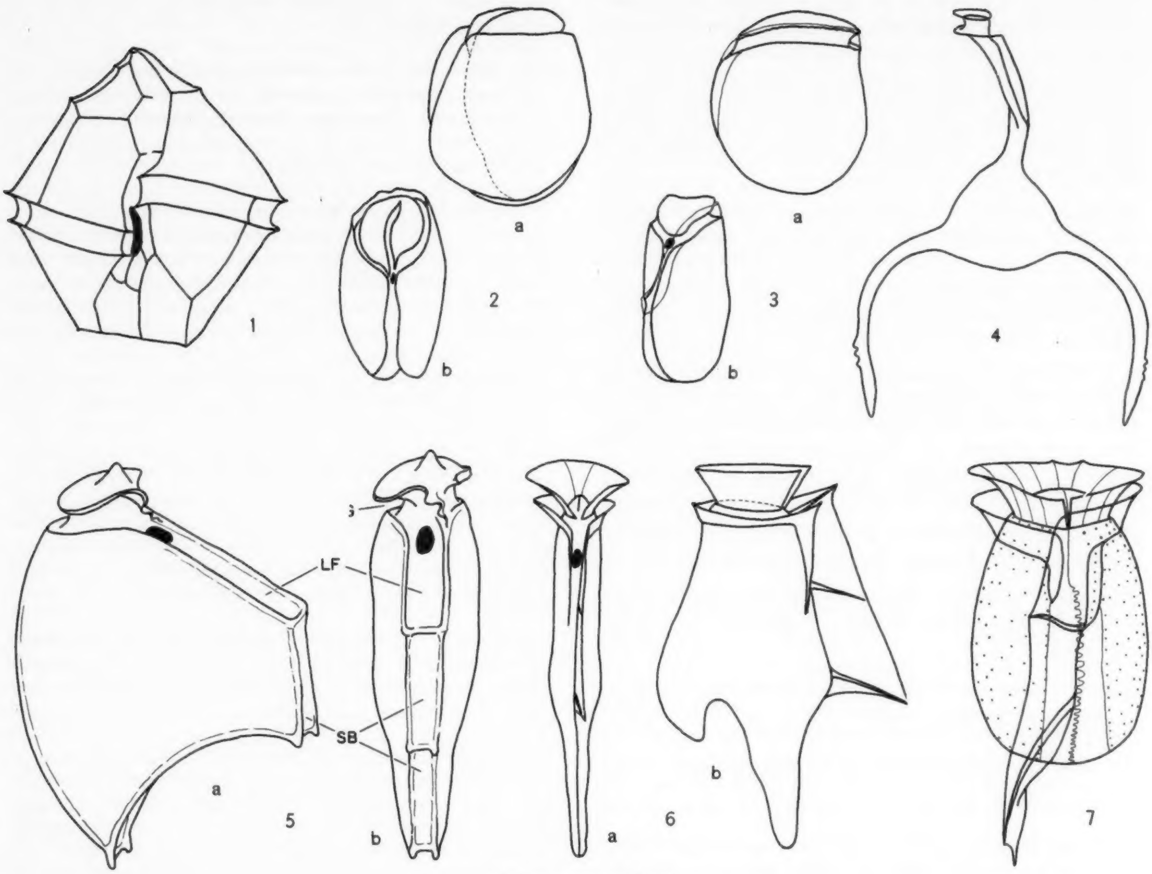
2) Variability in outline shape and in size.
As shown in plate 2, the outline shape goes through a series of imperceptible gradations from a basically oval form (in lateral view) to a basically triangular form. This results from the variable prominence of the ventral antapical point (horn). In the extreme oval forms it is not recognizable at all; in the extreme triangular forms it is as prominent as (although almost always shorter than) the dorsal one. The selected illustrations show only a sample of the variations. They range between such extremes that several isolated stages in the series might be thought to exhibit differences worthy of specific recognition. However, the many intermediate stages identify the phenomenon as infra- rather than intraspecific variability. As can be seen from the illustrations, there is a partial correlation between outline shape and size; the oval types tend to be smaller.

A similar variability in the outline shape of *N. pellucida* is unknown. In that species the triangular form, with subequal antapical horns, is the only form that has been observed.

3) Variability in surface features of the hypotheca.
The principal variables on the hypothecal surface are the ridges that separate the lateral surfaces from the sagittal band, and that cross the latter at the apical points and the antapical limit of the longitudinal furrow. In some specimens these ridges are prominent, and all the surfaces are clearly limited. At the other extreme are specimens in which none of the ridges are distinctly developed and it is impossible to distinguish the limits of the lateral surfaces or the several parts of the sagittal band. Intermediate between these are the majority of specimens, in which some of the ridges are clearly developed and others are only faint or not visible at all.

The ridge across the sagittal band at each antapical point merits special mention. This may be: a) completely absent, b) represented only by two short points rising from the junctions between lateral and sagittal surface, c) present as a low ridge no more conspicuous than those in other places, or d) developed as a crestlike structure of constant height or somewhat higher at the two lateral extremities. The last condition is the most common, although even within this category there is much variation.

4) Variablity in the wall.
In some specimens the wall is thin, transparent and uniform in appearance, the fine surface areolation being discernible only with difficulty. Other specimens appear dark and opaque and the surface areolation is accen-



TEXT-FIGURES 1–7

Diagrams to illustrate the morphological similarities of *Nannoceratopsis deflandrei* Evitt, n. sp., with the Dinophysiales (2–4, 6–7) and contrasts with the Peridiniales (1). All except *Nannoceratopsis* are Recent dinoflagellates, modified from illustrations given by Schiller (1933, 1937), who drew them from several different authors. Drawings are to slightly different scales. Flagellar pores in solid black.

1, *Gonyaulax polyedra* Stein, ventral view. 2, *Amphidinium sulcatum* Kofoid, a) left lateral view; b) ventral view. 3, *Thecadinium kofoidi* Kofoid and Skogsberg, a) left lateral view; b) ventral view. 4, *Triposolenia intermedia* Kofoid and Skogsberg, left lateral view. 5, *Nannoceratopsis deflandrei* Evitt, n. sp., a) right lateral view, slightly oblique; b) ventral view; G-girdle; LF-longitudinal furrow; SB-sagittal band. 6, *Dinophysis tripos* Gourret, a) ventral view; b) left lateral view. 7, *Dinophysis joergenseni* Kofoid and Skogsberg, ventral view.

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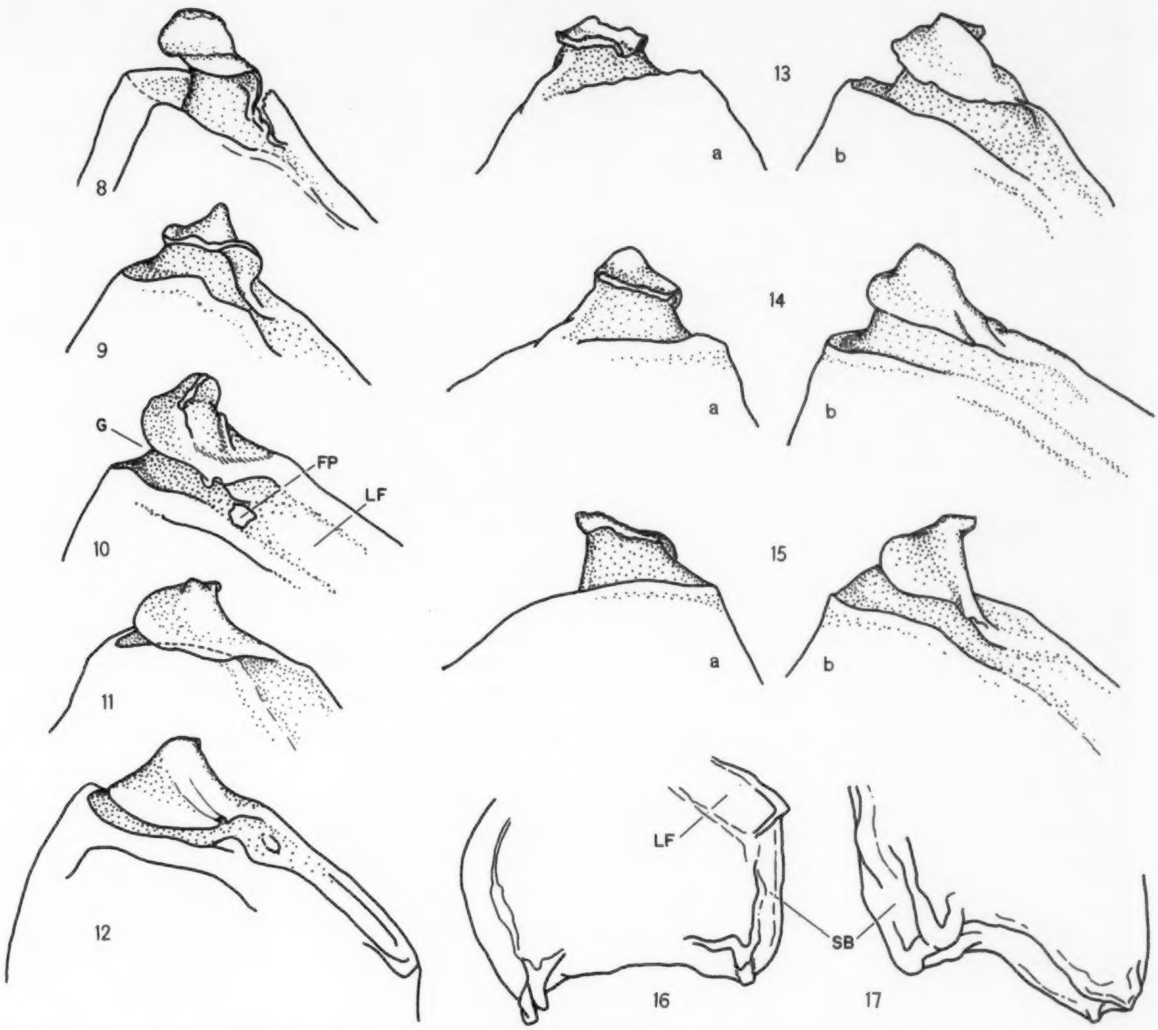
tuated. This variation in wall appearance is partly correlated with size and shape: a higher percentage of the oval and smaller specimens is clear, whereas most of the dark specimens are larger and/or triangular forms. However, large clear specimens and small dark oval ones occur, and part of an individual may be clear and the rest dark. The cause of the dark appearance is uncertain. It seems to be at least in part an optical effect (a variation in the refractive index related to differences in composition possibly accentuated by preservation?) rather than a true coloration of the wall. Most individuals of *N. deflandrei* (as also noted by Deflandre, 1938, in *N. pellucida*) accept stain poorly. The ones that do stain at all are almost without exception ones with clear walls – suggesting a compositional difference between the two types. Whether this variation is related to the living cells, or is wholly a preservational feature is unknown.



TEXT-FIGURES 8–17
Camera lucida drawings

8 *Nannoceratopsis pellucida* Deflandre. Detail of apical region, for comparison with succeeding figures; × 1300. Upper Jurassic, Utah; USNM 139390; R 9.7, + 18.0.

9–15 *Nannoceratopsis deflandrei* Evitt, n. sp. Details of apical region, showing variable appearance resulting chiefly from varied orientations of the flaplike projection above the girdle on the right side. Text-figs. 13–15 show right and left views of three individuals; × 1300. Lower Jurassic, Denmark. G-girdle; FP-flagellar pore; LF-longitudinal furrow; SB-sagittal band.

9, USNM 139384; R 20.1, + 14.2; 10, USNM 139383; R 21.8, + 6.3; 11, USNM 139384; R 17.7, + 12.0; 12, USNM 139384; R 18.8, + 3.7; 13, USNM 139386; R 4.5, + 15.2; 14, USNM 139383; R 16.9, + 9.1; 15, USNM 139384; R 0.7, + 11.4.

16–17 *Nannoceratopsis deflandrei* Evitt, n. sp. Two specimens of triangular form showing sagittal band, longitudinal furrow and ridges bounding them; × 800. Lower Jurassic, Denmark.
16, USNM 139383; R 26.7, + 5.5; 17, USNM 139384; R 21.3, + 7.6.

Comparison: N. deflandrei differs from *N. pellucida* Deflandre, the only other described species, as follows:

1) *N. deflandrei* is shorter and wider (in lateral view). The illustrated specimens of *N. pellucida* of Deflandre (1938, pl. 8) have a length: width ratio of 1.6, whereas the mean of 100 two-pointed individuals of *N. deflandrei* is 1.2, and 1.6 is the extreme reached only by one specimen.

2) The antapical points are less strongly and, apparently, much more variably developed in *N. deflandrei;* the margin between them is not so deeply concave.

3) In *N. deflandrei* the ridges bounding the lateral surfaces are commonly more prominent, the sagittal band is relatively wider, and the longitudinal furrow is more clearly delimited.

4) The wall of *N. deflandrei* is apparently somewhat thicker and less flexible than in *N. pellucida*, in which it is more commonly creased and folded.

5) The infraspecific variability of *N. deflandrei* is greater than that of *N. pellucida.*

Deflandre studied approximately 30 specimens of *N. pellucida* when he established the species. I have seen a comparable number in preparations from the Curtis formation from Utah. In the Utah material all the specimens encountered showed the two antapical horns to be more or less equally developed. There was no suggestion of a specimen anywhere approaching the ovoid variants of *N. deflandrei* in which the ventral projection is greatly reduced, and which amount to nearly 25 percent of the specimens of that species. If such variants exist in *N. pellucida*, they are very infrequent.

Nannoceratopsis pellucida Deflandre, 1938, **emended**
Plate 1, figures 15–18; Plate 2, figures 30, 31;
text-figure 8

Nannoceratopsis pellucida Deflandre, 1938*a*, Acad. Sci. Paris, C. R., vol. 206, p. 688, text-fig. 5; nomen nudum. – Deflandre, 1938*b*, Stat. Zool. Wimereux, Trav., vol. 13, p. 183–184, pl. 8, figs. 8–12. – Cookson and Eisenack, 1958, Roy. Soc. Victoria, Proc., n. s., vol. 70, pl. 1, pp. 52-53, pl. 10, figs. 5–6, text-fig. 19.

Diagnosis: Outline subtriangular; two antapical horns about equal, long and large, separated by deep concavity. Variability slight; specimens having one horn greatly reduced are unknown. Sagittal band narrow; limiting ridges commonly narrow and faint so that longitudinal furrow is not conspicuously differentiated from rest of band. Typical size about 88 by 45μ in lateral view.

Forma corporis subtriangula; duo cornua antapicalis subaegualia, et longa et magna, separata cavo profundo. Forma parve varia; exempla cum uno corno magne redacto ignota. Vinculum sagittale angustum; costae circum vinculum saepe angustae et obscurae ut sulcus non manifesto separatus de reliquo vinculi. Magnitudo solita corporis fere 88 × 45μ visi ab latere.

Types: Holotype: Deflandre: 1938*a*, pl. 8, fig. 10; Oxfordian, Villers-sur-Mer, France. Hypotypes figured in this paper are in the U.S. National Museum; USNM numbers and coordinates tabulated in plate and figure explanations.

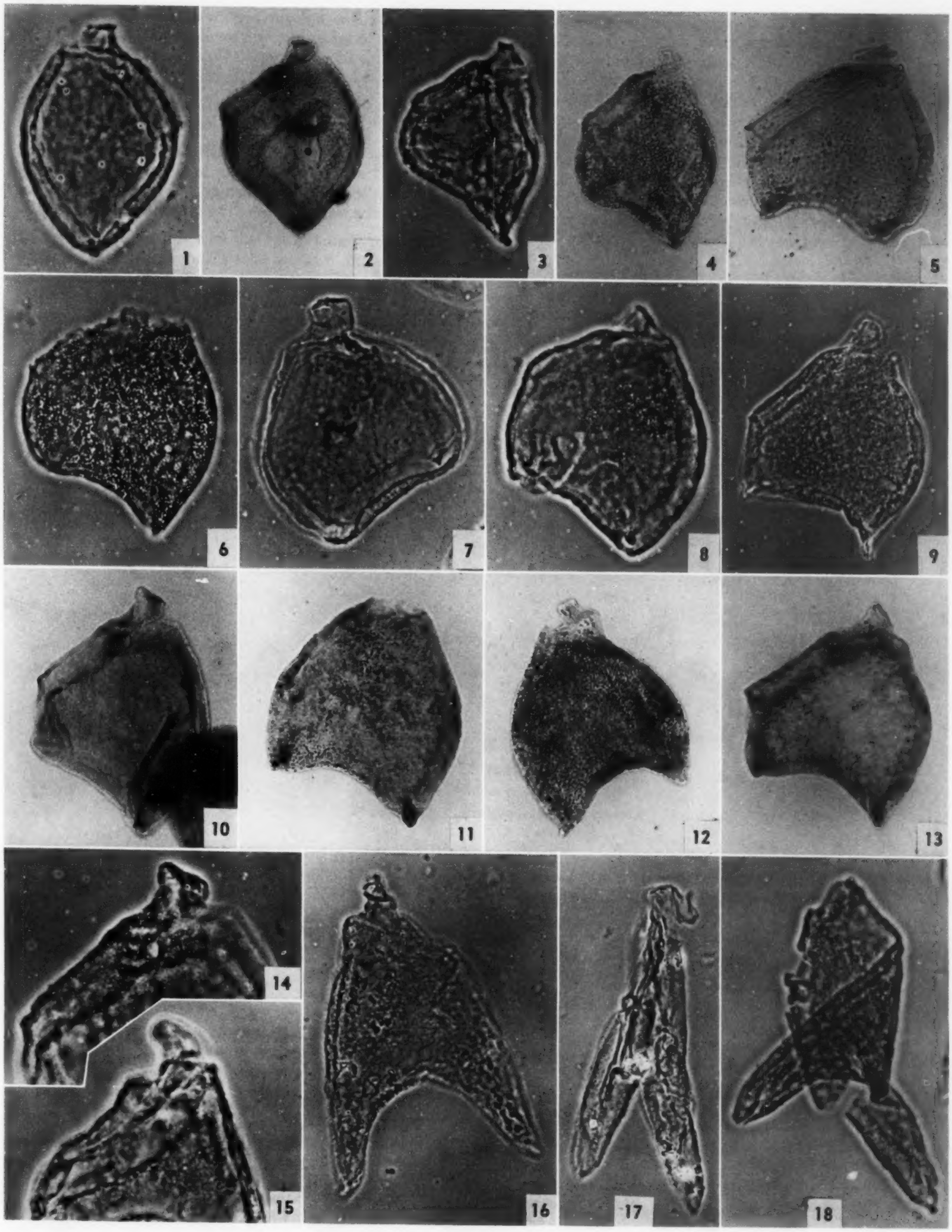
Material and occurrence: This species is here reported for the first time from North America. Well preserved

PLATE 1

Figures 14 and 15 × 1000; all others × 600. Figures 2, 3, 4, 10–13 bright field; others, phase contrast.

1–14 *Nannoceratopsis deflandrei* Evitt, n. sp.
Figures 1–12, 14 Paratypes; Lower Jurassic, Denmark.
1 USNM 139388; R 18.0, +6.4
2 USNM 139383; R 17.2, +14.5
3 USNM 139385; R 12.6, +5.4
4 USNM 139388; R 25.9, +9.8
5 USNM 139386; R 11.0, +9.7
6 USNM 139385; R 7.6, +4.0
7 USNM 139383; R 14.1, +7.8
8 USNM 139384; R 2.7, +5.0
9 USNM 139383; R 29.0, +4.9
10 USNM 139383; R 21.8, +6.3
11 USNM 139388; R 18.1, +10.7
12 USNM 139388; R 26.4, +9.5
13 USNM 139385; R 30.4, +5.6; Holotype
14 USNM 139383; R 21.8, +6.3

15–18 *Nannoceratopsis pellucida* Deflandre
Hypotypes; Upper Jurassic, Utah.
15 USNM 139390; R 20.7, +17.1
16 USNM 139391; R 3.2, +5.1
17 USNM 139391; R 6.0, +4.1
18 USNM 139391; R 33.1, +11.8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specimens occur (35 specimens in four slides were examined) in slides prepared from a sample of the Curtis formation taken about 60 feet below the contact with the overlying Morrison formation in a surface section exposed in Section 26, T. 4 S., R. 23 E., Dinosaur National Monument, Uintah County, Utah. More abundant than *N. pellucida* in the same sample are *Gonyaulax jurassica* Deflandre and *Scriniodinium crystallinum* (Deflandre). These three conspicuous and distinctive species were originally described (Deflandre, 1938*b*) in the same association in the Oxfordian marls of Villers-sur-Mer in western France.

Remarks on specific characters: Careful study of the available specimens of *N. pellucida* from Utah confirms that the chief morphological features described in *N. deflandrei* also occur in this species:

1) A narrow sagittal band is present, separated from the two large lateral surfaces by narrow ridges (pl. 1, fig. 18).

2) A longitudinal furrow can be distinguished in the apical portion of this band on the ventral side (pl. 1, fig. 15).

3) A girdle (the oblique furrow observed by Deflandre) enters the longitudinal furrow obliquely near its apical end. The girdle continues around the dorsal surface and ends on the left side (pl. 1, figs. 15–17).

4) A narrow ridge joins the minute epitheca ventrally with the lefthand edge of the longitudinal furrow.

5) A somewhat undulated flap begins on the ridge mentioned above, then expands along the apical edge of the girdle on the right side. A narrow thickening occurs on the apical edge of the girdle on the left side.

It is not surprising that Deflandre failed to call attention to some of the features noted above, nor that he interpreted others somewhat differently than I do. They are, for the most part, much more difficult to discern in *N. pellucida* than in *N. deflandrei*. This seems to result primarily from the more delicate construction of *N. pellucida*. Its wall is thinner and the ridges at the junctions between the lateral surfaces and the sagittal band are less prominent. However, having the morphology of *N. deflandrei* in mind, all the essential structures can be recognized in the type species. The differences between the two species, including their variability, are discussed under *N. deflandrei*.

PLATE 2

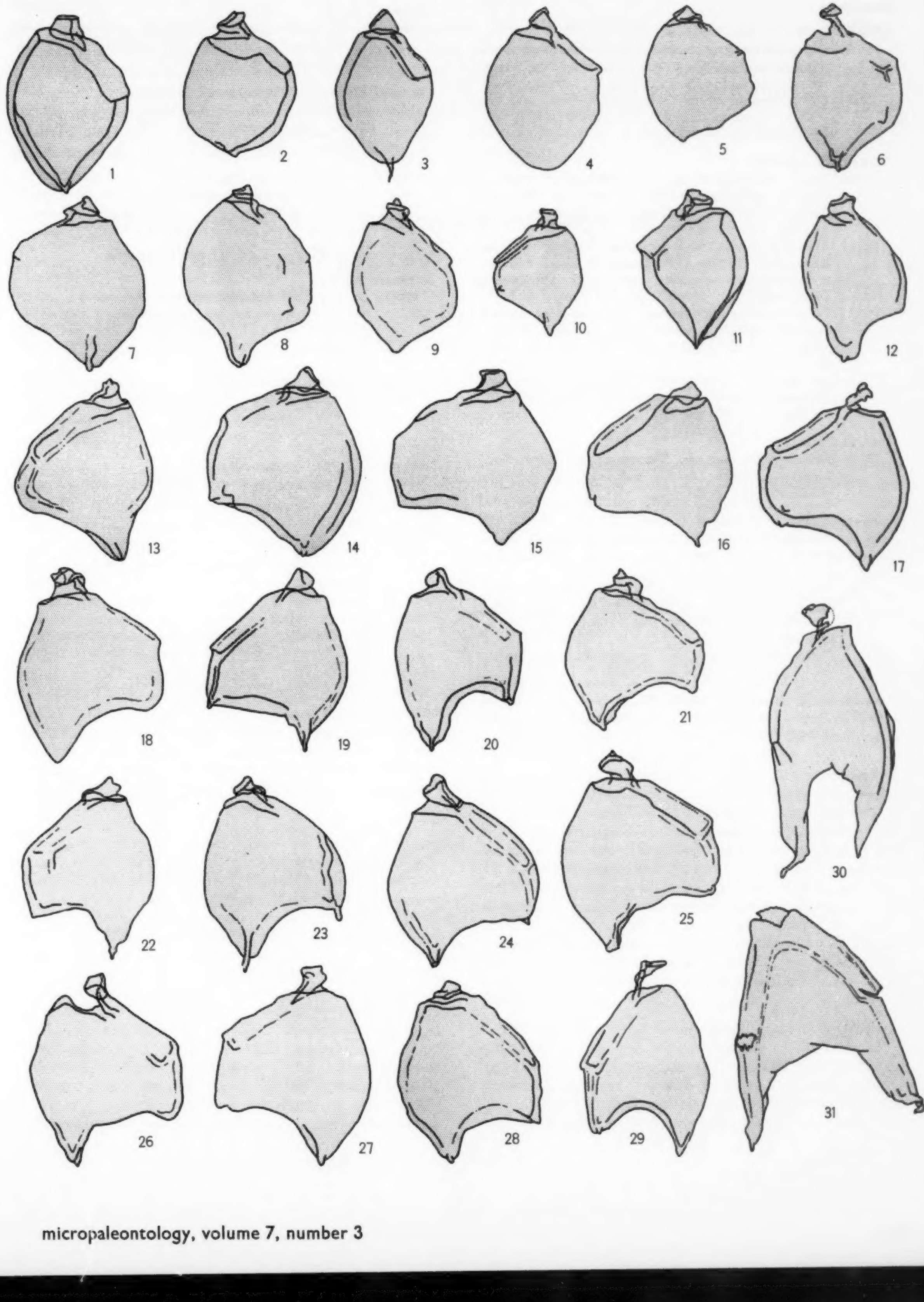
Camera lucida drawings; all figures × 500.

Nannoceratopsis deflandrei Evitt, n. sp.
Paratype specimens to illustrate variable morphology within the species; Lower Jurassic, Denmark.

1 USNM 139388; R 18.0, +6.4
2 USNM 139384; R 28.7, +0.7
3 USNM 139384; R 12.5, +7.3
4 USNM 139384; R 15.3, +2.9
5 USNM 139384; R 5.5, +14.2
6 USNM 139384; R 12.7, +11.8
7 USNM 139384; R 14.6, +8.5
8 USNM 139387; R 21.4, +13.1
9 USNM 139387; R 8.5, +15.1
10 USNM 139386; R 5.5, +10.6
11 USNM 139386; R 11.8, +10.1
12 USNM 139386; R 5.8, +6.4
13 USNM 139383; R 21.6, +14.0
14 USNM 139384; R 2.7, +5.0
15 USNM 139384; R 20.0, +5.1
16 USNM 139384; R 8.7, +4.5
17 USNM 139384; R 9.5, +6.7
18 USNM 139386; R 3.7, +12.2
19 USNM 139383; R 29.0, +4.9
20 USNM 139384; R 15.5, +13.7
21 USNM 139384; R 11.0, +14.0
22 USNM 139383; R 7.9, +4.5
23 USNM 139384; R 20.0, +14.2
24 USNM 139386; L 0.4, +14.5
25 USNM 139386; R 1.6, +14.9
26 USNM 139384; R 12.0, +8.2
27 USNM 139384; R 18.3, +9.2
28 USNM 139384; R 3.6, +4.6
29 USNM 139384; R 19.6, +6.3

Nannoceratopsis pellucida Deflandre
Hypotypes; Upper Jurassic, Utah.

30 USNM 139390; R 31.2, +18.1
31 USNM 139391; R 1.9, +10.9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ABSTRACT

The results of a micropaleontological study of material collected from Ain Maqfi, Farafra Oasis, Egypt, are presented. Although this area was treated previously by LeRoy, this paper records in detail the planktonic foraminifera of the section, as well as the reefal assemblages that are intercalated in and cap the Esna shale of this oasis. The planktonic forms have been given only moderate consideration by previous workers. The age of the Esna shale of Farafra is established as upper Paleocene; many of the primitive Nummulites *and* Alveolina *species that occur in this succession are thus shown to be of upper Paleocene age. This work demonstrates by paleontological methods the presence of an unconformity between the Maestrichtian and the upper Paleocene, thus resolving an 80-year-long controversy.*

The geology and micropaleontology of the Farafra Oasis, Egypt

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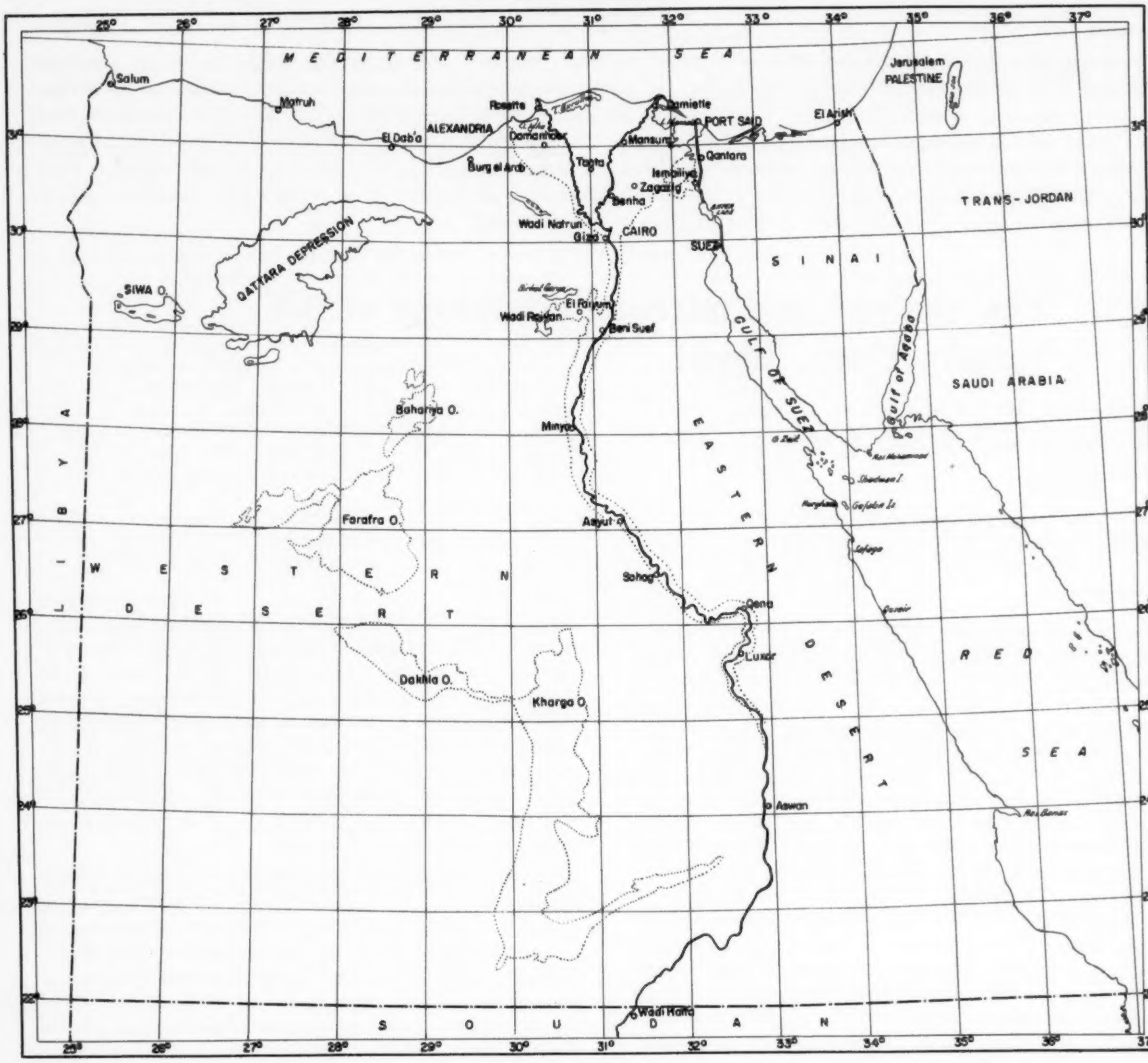
INTRODUCTION

The geology and paleontology of the Farafra Depression, an isolated oasis in the heart of the Libyan Desert (text-fig. 1), have attracted the attention of workers for a long time. The geology of this oasis has been made famous by the classic work of Zittel (1883), who took the shale beds that form the slopes of this oasis as representing the lowermost beds of the Libyan Stage and as the type locality for determining the Cretaceous and Eocene contact. The exceedingly important paleontological work of Schwager (1883) and de la Harpe (1883) on Zittel's collections from this oasis had far-reaching effects on the thinking of many later workers. Reichel (1936) and Schaub (1951) restudied the larger foraminifera of Zittel's collections and concluded that the species collected from the slopes of these lowermost Tertiary rocks represent some of the most primitive and earliest stocks of the genus *Alveolina* and the family Nummulitidae, from which many of their later evolutionary lines were developed.

Intelligent attempts were made by these authors, working on collections housed thousands of miles away from Farafra, to read through the notes of Zittel and later workers to ascertain the age of the beds from which these primitive fossil stocks were recovered. Both Reichel (1936) and Schaub (1951) considered these beds Montian, and the evolutionary trees that they developed from the primitive stocks of Farafra were fitted to this age. However, conclusive evidence for the age of these lowermost Tertiary beds was still lacking. Although the excellent detailed micropaleontological work carried out by LeRoy (1953) added much to our knowledge of the foraminifera of these basal beds, it did not give a definite answer to the problem of their age, and in fact, raised several questions and doubts concerning the previously accepted theory of continuous sedimentation between the Cretaceous and the Lower Tertiary beds in Farafra. He recorded an unconformity between the Chalk, which makes up the floor of the depression, and the famous foraminifera-bearing Esna shales that make up the slopes of this oasis. Working at a time when the microfaunal successions of the Cretaceous and Lower Tertiary rocks of the world in general, and of Egypt in particular, were not established, he was unable to assign a definite age to these important slope-forming beds of this oasis.

The advances made in recent years in the study of the Upper Cretaceous—Lower Tertiary foraminifera have made it possible to establish an intercontinental correlation scheme based on the limited vertical distribution and wide lateral extension of the planktonic foraminifera. The latter have not been reported in detail by previous workers on the Farafra area. In the present paper, the distribution of these important species is recorded in detail in an attempt to date conclusively the units that make up the classic Farafra section. The foraminiferal assemblages within and at the top of the Esna shale succession of the oasis, which were not given much consideration in LeRoy's work (1953), are also described. These fossils are especially important, for they represent some of the oldest records in many lineages. The recording of these assemblages in a well-dated stratigraphic column based on planktonic foraminifera forms one of the most significant results of this study.

This paper is an outgrowth of a study conducted by the junior author for the Master's degree at the University of Cairo. The senior author selected the problem, carefully checked all paleontological identifications, prepared the final manuscript, and is responsible for the taxonomic and geologic conclusions.



TEXT-FIGURE 1

MAP OF EGYPT SHOWING THE LOCATION OF FARAFRA OASIS

GEOLOGY

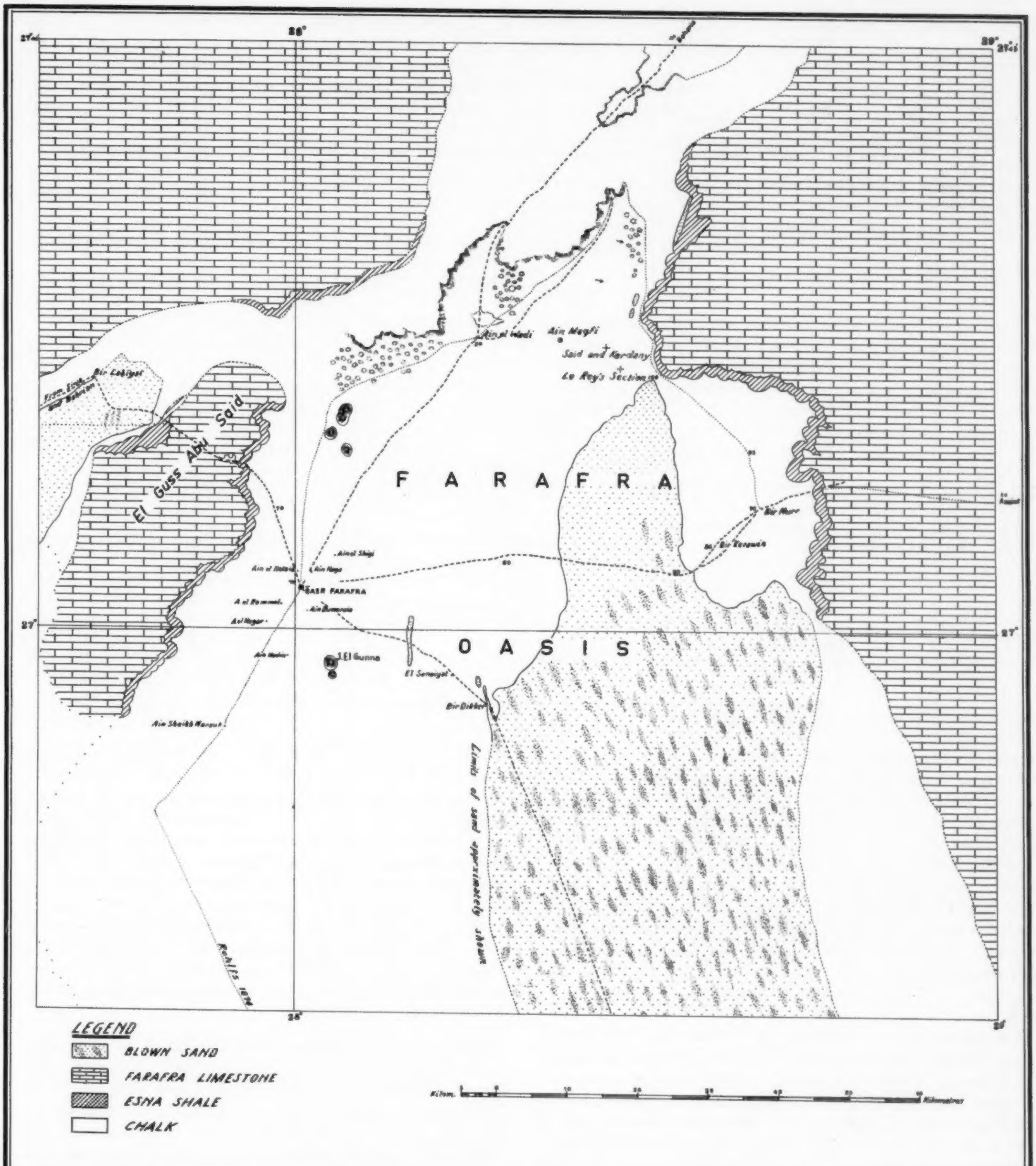
The geology of the Farafra Oasis is relatively simple. It has been dealt with by Zittel (1883) and by Beadnell (1901). Three extensive mappable rock units make up the floor and slopes around this oasis, the areal distribution of which is shown on the geologic map (text-fig. 2). These units are, from top to bottom, the Farafra limestone, the Esna shale, and the Chalk.

THE CHALK

The depression of the Farafra Oasis is cut in a white chalk bed which is part of an extensive mappable rock unit known in the literature as the Chalk, which covers large tracts of the southern Libyan Desert. This unit has been equated in the past with the Danian, following the practice started by Zittel (1883). Later work has demonstrated that this widely distributed rock unit is of different ages in different places (Said and Kenawy, 1956; Nakkady, 1957). In Farafra it was assigned a Maestrichtian age by LeRoy (1953).

THE ESNA SHALE

Overlying the Chalk is a series of slope-forming green shales that belong to the famous Esna shale rock unit. This unit is of more or less uniform thickness along both the eastern and western escarpments of the oasis. In the



TEXT-FIGURE 2

GEOLOGIC MAP OF FARAFRA OASIS (AFTER BEADNELL, 1901)

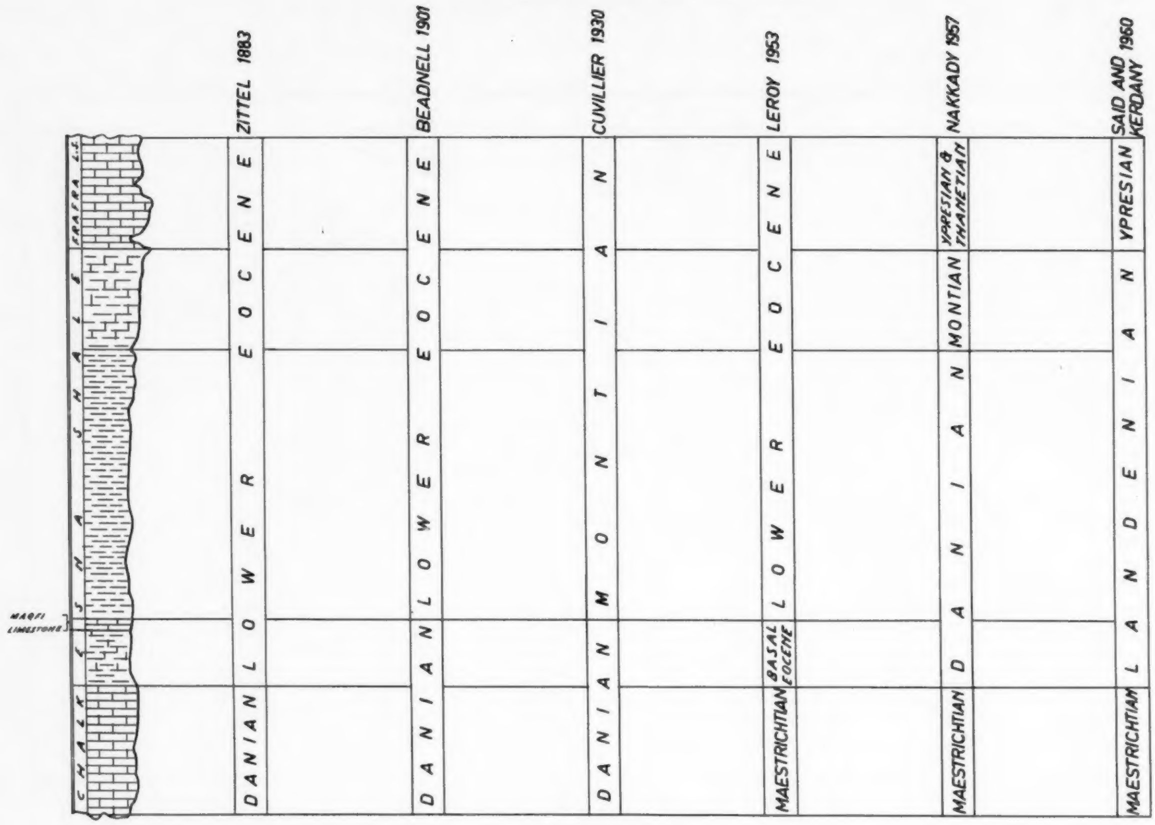


CHART 1
AGES OF THE UNITS OF THE FARAFRA SECTION ASSIGNED BY PREVIOUS WORKERS

eastern scarp, from which the section studied in this paper, as well as LeRoy's, was taken, the thickness of the Esna shale ranges from 120 to 160 meters. In the western slope of the oasis, at El Guss Abu Said plateau, Zittel and Beadnell both reported a 150-meter thickness for the Esna shale. By an increase in calcareous material and a corresponding loss of clastics, these shales pass into the Farafra limestone above. Cutting through the shale is a thin limestone bed of apparently large areal extent. This bed is here given the name of Maqfi limestone member.

AGE

The age of this unit has been in controversy for a long time. Chart I summarizes the ideas of different workers on the age of this unit. Zittel (1883) assigned a lower Eocene age to these beds on the basis of the presence of *Nummulites deserti*, *N. fraasi*, and *Operculina libyca* in them. He took this part of the section as representing the lowermost part of his lower Libyan stage.

Cuvillier (1930) took this unit as the type of the oldest Eocene, or "Montian," in Egypt. LeRoy (1953) carried out an extensive study of the foraminiferal content of these shales and subdivided the section into a lower unit (unit IV) and an upper unit (unit II), separated by a thin limestone bed (unit III). According to LeRoy, the microfaunas of unit IV "appear to be allied to those of the Velasco shales of Mexico," and, in the absence of better knowledge of the Egyptian Paleocene, LeRoy favored allocating this unit to the basal Eocene. LeRoy's unit II includes a rich microfauna which, according to LeRoy, permitted zonation and which he compared with the Wilcox assemblages of Alabama (lower Eocene). LeRoy's unit III is a hard, thin limestone bed containing *Nummulites deserti* and *Operculina libyca*, which he dated as lower Eocene.

Nakkady (1957) examined LeRoy's data and attempted to fit them into the time-scale that he had devised. He assigned LeRoy's unit IV and the lower part of unit II (*Bulimina farafraensis* zone of LeRoy) to the upper Danian, characterized by the presence of sharp-keeled *Globorotalia* species. Nakkady assigned the upper part of the Esna shale (*Eponides lotus* fauna of LeRoy) to the Montian, characterized by the presence of *Nummulites deserti*. To make this picture logical and to stress the value of *Nummulites deserti* as an index fossil for the

Montian, Nakkady questioned the existence of LeRoy's unit III, which carries *Nummulites deserti* and which is intercalated within the Esna shale proper. The present work shows that this limestone unit (the Maqfi limestone member) is intercalated in the Esna shale and is a persistent unit of considerable lateral extent. *Nummulites deserti* is shown in this work to occur side by side with the sharp-keeled *Globorotalia* species of unquestionable Landenian age, and is therefore regarded as being of the same age as the *Globorotalia velascoensis-simulatilis* assemblage rather than of a later age than that assemblage, as believed by Nakkady (1957, 1959).

RELATIONS OF THE CHALK AND THE ESNA SHALE

The Esna shale unit was stated to be absolutely conformable with the underlying chalks by Zittel (1883). This observation led Zittel to advocate the theory of continuous sedimentation between the Cretaceous and Eocene; he remarked that "there is no sharp demarcation between the two systems and no disturbance in the succession; there are no intercalated fresh-water deposits in any part of the section, and there is no trace of a hiatus between the two systems." Generalizing from this observation, Zittel thought that the Libyan Desert offers one of the rare complete records in the world of marine sedimentation during the Upper Cretaceous and lower Eocene where no volcanic activity occurred during the transition and where even lithologic change between the two systems is not sharply marked. He considered this discovery to be one of the greatest achievements of the Rolf expedition, which he accompanied.

Zittel's conclusions (1883) seem to have left a marked impression on the thinking of many later geologists, and the Farafra section is accepted by almost all authorities as the type section of a complete record between the Cretaceous and Eocene.

Beadnell (1905) emphatically pointed out, from examples in widely separated areas, particularly in the Esna-Aswan reach of the Nile Valley, the perfectly conformable relations of the Cretaceous and Eocene systems in southern Egypt, although the same author (1901, p. 21), in his classic work on Farafra, had indicated his suspicion of an unconformable passage between the Cretaceous (equated by him with the Chalk rock unit) and Eocene (equated by him with the Esna shale rock unit). Cuvillier (1930) took the classic section of Farafra as one of the rare examples in Egypt of continuous sedimentation and of the presence of the "Montian," which he did not recognize except in Farafra and the northern part of southern Galala.

An unconformity was suspected by Beadnell (1901) and stated to occur on the strength of field evidence by LeRoy (1953). The field evidence for the presence of an unconformity is in harmony with the conclusions of the present work based on a study of the vertical distribution of the foraminifera. The typical *Globotruncana–Heterohelix* assemblage of Maestrichtian age recorded from the Chalk unit in Farafra is followed immediately by the sharp-keeled *Globorotalia* assemblage in the overlying Esna shale. The intervening *Globigerina*-rounded *Globorotalia* assemblage of Danian age is missing, indicating a paleontological break.

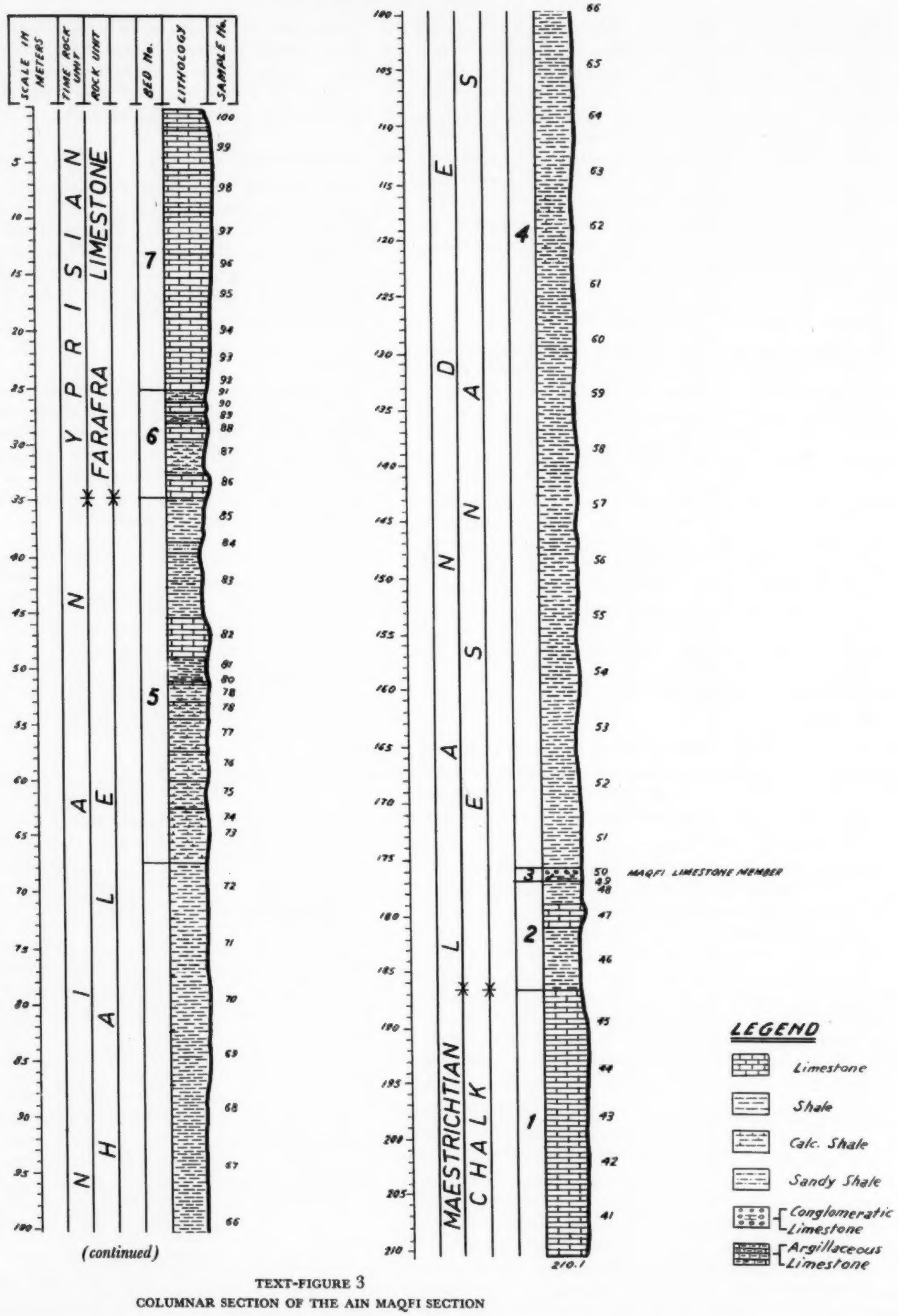
THE FARAFRA LIMESTONE

Overlying the Esna shale is a 34-meter thick-bedded, massive, tan to buff alveolinid limestone, argillaceous in the lower part, which is of limited lateral extent in the Farafra area. This unit, which has been termed the Farafra limestone by Said (1960), represents the reefal facies of the Ypresian in Egypt. It has been dated as lower Eocene by all workers.

MATERIAL

The material upon which this study is based comes from a section at Ain Maqfi, Farafra Oasis (lat. 27°24′ N.; long. 28°28′ E.). Acknowledgment is due the Sahara Petroleum Company for making this section and its samples available. A summary of the section is given below. Text-figure 3 is a columnar section showing the positions of the samples analyzed.

Rock unit	Bed no.	Description	Thickness in meters	Total thickness in meters
Farafra limestone	7	Limestone, thick-bedded, white to buff, recrystallized and hard, with abundant *Alveolina* species.	24	211
ESNA SHALE	6	Alternating calcareous shale and argillaceous limestone.	10	178
Maqfi limestone member	5	Calcareous shale with occasional thin limestone beds.	32	177
	4	Green to greenish gray fissile shale, hard and brittle in places.	110	145
	3	Hard, gray to tan limestone, conglomeritic, allochthonous in part.	1	35
	2	Gray to greenish fissile shale.	10	34
Chalk	1	White, massive, compact, moderately indurated chalk, forming a ledge. Base unexposed.	24	24



TEXT-FIGURE 3
COLUMNAR SECTION OF THE AIN MAQFI SECTION

THE FORAMINIFERA

Previous literature

The micropaleontology of the Farafra Oasis has been the subject of research by Schwager (1883), de la Harpe (1883), and LeRoy (1953). In fact, the Farafra Oasis was one of the first localities in Egypt to be studied, and is the type locality of many well-known foraminiferal species. Schwager, describing the Rolf expedition collections, singled out El Guss Abu Said as of special interest, for it "represents the deepest part of the Egyptian Eocene." He described fourteen new species and a total of nineteen species from the lower part of the Esna shale unit: *Anomalina scrobiculata* Schwager, *Cristellaria gussensis* Schwager, *C. isidis* Schwager, *Discorbina praecursoria* Schwager, *D. simulatilis* Schwager, *Dentalina inornata* d'Orbigny, *Glandulina caudigera* Schwager, *G.* cf. *elongata* Bornemann, *Globigerina* cf. *cretacea* d'Orbigny, *Haplophragmium bradyi* Schwager, *Lagena* cf. *lineata* Williamson, *Marginulina dentalinoides* Schwager, *M. gussensis* Schwager, *Operculina libyca* Schwager, *Orbitoides nudimargo* Schwager, *Plecanium niloticum* Schwager, *Polystomella*(?) *obscura* Schwager, *Truncatulina colligera* Schwager, and *Virgulina* aff. *schreibersi* Czjzek.

Schwager described thirteen species from the upper part of the Esna shale unit, which he called the "Operculinen-Horizont" (bed no. 5 of our section): *Anomalina insecta* Schwager, *Discorbina calcariformis* Schwager, *D. umbonifera* Schwager, *D. rigida* Schwager, *Globigerina bulloides* d'Orbigny, *Heterostegina ruida* Schwager, *Operculina libyca* Schwager, *Pulvinulina moelleri* Schwager, *P. semiplecta* Schwager, *P. lotus* Schwager. This fauna is identical with the *Eponides lotus* fauna which occurs in the upper part of LeRoy's unit II. From the overlying "Alveolinen-Horizont" (our Farafra limestone), Schwager described two new species: *Alveolina (Flosculina) decipiens* Schwager and *Discorbina sphaeruligera* Schwager.

De la Harpe (1883) described three well-known species of *Nummulites* from the Esna shale unit of El Guss Abu Said. These were *Nummulites fraasi* de la Harpe, *N. solitaria* de la Harpe, and *N. deserti* de la Harpe.

LeRoy (1953) identified some 131 species from the Maqfi section of the Farafra Oasis. Special emphasis was placed on the Esna shale fauna, whereas those of the Chalk and the Farafra limestone units were given only moderate consideration. He divided the section, according to its foraminiferal content, into a lower Maestrichtian unit A and four lower Tertiary units: IV, III, II and I. The upper limit of the Maestrichtian unit is characterized by an abundance of *Globotruncana* and *Guembelina* species and coincides with the Chalk-shale boundary.

Unit IV is characterized by the absence of *Globotruncana* and *Guembelina* and by the appearance of *Globorotalia velascoensis* (Cushman) (basal Eocene or ?Paleocene), and unit III is characterized by the presence of *Nummulites deserti* de la Harpe and *Operculina libyca* Schwager, which, according to LeRoy, mark the advent of the lower Eocene. Unit II is divided tentatively into a lower *Bulimina farafraensis* zone and an upper *Eponides lotus* zone. The lower *Bulimina farafraensis* zone is further subdivided into a *Loxostomum applinae* faunule and an upper *Cornuspira polygyra* faunule.

Distribution in the section studied

Some 180 species of foraminifera were distinguished and recorded from the Ain Maqfi section. Fifty-seven samples were studied, five of which (nos. 41–45) come from the Chalk rock unit. Thirty-seven samples (nos. 46–85) are from the Esna shale; of these, sample no. 50 was taken from a thin allochthonous limestone bed intercalated in the Esna shale (the Maqfi limestone member). Fifteen samples (nos. 86–100) are from the Farafra limestone. The position of these samples is shown in the accompanying columnar section (text-fig. 3). The fauna of each of these rock units is given below. It should be pointed out that these rock units at Maqfi are time-rock units, for the time boundaries drawn in the section coincide with the lithologic breaks.

The Chalk foraminifera

The Chalk samples contain a characteristic fauna that is quite different from those of the higher samples. These samples are made up almost entirely of the following planktonic species: *Globotruncana arca* (Cushman), *G. cretacea* Cushman, *G. esnehensis* Nakkady, *G. gansseri* Bolli, *G. rosetta* (Carsey), *Heterohelix globulosa* (Ehrenberg), *H. reussi* (Cushman), *H. ultimatumida* (White), *Planoglobulina acervulinoides* (Egger), *Pseudotextularia elegans* (Rzehak), *Pseudoguembelina excolata* (Cushman), *Racemiguembelina fructicosa* (Egger), and *Rugoglobigerina* cf. *jerseyensis* Olsson. Other distinctive species which are restricted to this unit are: *Bolivinoides draco draco* (Marsson), *Bolivina decurrens parallela* Said and Kenawy, *B. incrassata* Reuss, *Bulimina prolixa* Cushman and Parker, *Gavelinella pertusa* (Marsson), and *Neoflabellina rugosa leptodisca* (d'Orbigny).

The Maestrichtian age of this fauna is obvious. All authorities agree that *Globotruncana gansseri* Bolli, *G. arca* (Cushman), *G. rosetta* (Carsey), and *G. cretacea* Cushman are markers of the Maestrichtian (Bolli, 1951, 1957*a*; Dalbiez, 1955; and others). Furthermore, the presence of *Bolivinoides draco draco* (Marsson) gives further evidence of the Maestrichtian age of this unit (Hiltermann and Koch, 1950).

The diversified *Globotruncana* assemblage in the Farafra chalk unit indicates deposition in an open-sea environment. In contrast, the Kharga Maestrichtian fauna (Nakkady, 1959) and that of an undescribed Maestrichtian formation (Said, MS.) contain fewer planktonics and seem to have been deposited in a nearshore muddy facies.

The Esna shale foraminifera

The Chalk is followed by another unit comprising Esna shale samples nos. 46–85, which contain the distinctive sharp-keeled forms *Globorotalia velascoensis* (Cushman), *G. simulatilis* (Schwager), *G. colligera* (Schwager), *G. angulata abundocamerata* Bolli, and other *Globorotalia* species, together with *Chiloguembelina subtriangularis* Beckmann, *C. wilcoxensis* (Cushman and Ponton), and *Zeauvigerina aegyptiaca* Said and Kenawy. Table 1 shows the vertical distribution of the planktonic species recorded in this section.

This assemblage is clearly of Landenian (upper Paleocene) age. Many of the elements of this fauna are widely distributed and have been used for intercontinental correlation of the rocks of this age (Loeblich and Tappan, 1957; Bolli, 1957*b*). The presence of *Zeauvigerina aegyptiaca* Said and Kenawy, which has hitherto been recorded from Landenian rocks in Sinai (Said and Kenawy, 1956) and in Trinidad (Beckmann, 1957), seems to add more emphasis to the importance of this species as an index fossil for this age.

An examination of Table 1 permits a tentative zonation to be made. The lower 50 meters of the Esna shale (samples 46–58) are characterized by the presence in abundance of *Globorotalia simulatilis* (Schwager), *G. velascoensis* (Cushman), *Chiloguembelina subtriangularis* Beckmann, *Globorotalia varianta* (Subbotina), *G. pseudomenardii* Bolli, and *Zeauvigerina aegyptiaca* Said and Kenawy, the latter species being restricted to the lower 16 meters of this zone. It is interesting that LeRoy regarded *Globorotalia velascoensis* (Cushman) as a valuable zone fossil for the lower Esna shale member (that part of the shale which lies below the Maqfi limestone member). In the present work it is noted that this species continues above the limestone member into the lower part of the upper Esna shale. The chart given by Nakkady (1959) for the distribution of species in Gebel Um Elghanayem, Kharga Oasis, shows that *Globorotalia velascoensis* (Cushman) characterizes the lower part of Nakkady's upper Danian (our Landenian). It seems, therefore, that this fossil is of regional value, at least in the Western Desert of Egypt.

Following this zone there is another characterized by the absence of the *Globorotalia velascoensis* (Cushman) assemblage and the extended presence of *Globorotalia colligera* (Schwager), *G. esnaensis* (LeRoy), *G. pentacamerata* Subbotina, *G. convexa* Subbotina, and *G. pseudoscitula* Glaessner, the latter two not extending beyond the lower 70 meters of this zone. The uppermost part of this zone coincides with LeRoy's *Eponides lotus* zone. The latter is a reefal species which is found in the upper calcareous shale facies of the Esna shale. It is associated with abundant *Nummulites deserti* de la Harpe, *N. fraasi* de la Harpe, *N. solitarius* de la Harpe, *Operculina libyca* Schwager, *O. canalifera* d'Archiac, and *Discocyclina nudimargo* (Schwager). Table 1 gives the vertical distribution of the reefal species associated with the calcareous beds in the succession. This table shows that *Nummulites deserti* and *N. fraasi* are not restricted in occurrence to the horizons above the sharp-keeled *Globorotalia* species, as stated by Nakkady (1957, 1959), but are found also in the Maqfi limestone member, well below the horizon of the explosive appearance of *Nummulites*. *Nummulites deserti* de la Harpe is taken, therefore, as an index fossil for the Landenian (upper Paleocene). Text-figure 4 is a photomicrograph of sample 50 (Maqfi limestone member) showing *Nummulites deserti* de la Harpe lying side by side with the characteristic Landenian fossil *Globorotalia simulatilis* (Schwager). This conclusion is in harmony with the stratigraphic range given by Schaub (1951) for these *Nummulites*, which he studied from Farafra. The Egyptian Paleocene, as conceived in this paper, includes only the primitive *Nummulites deserti* de la Harpe, *N. fraasi* de la Harpe, and *N. solitarius* de la Harpe. Contrary to the findings of other authors in other parts of the world (Nagappa, 1959), Nakkady's extended Paleocene includes the great majority of Egyptian *Nummulites*.

Another reefal fossil found in this Paleocene unit and especially abundant in the Maqfi limestone member (sample 50) is *Alveolina ovulum* Stache (text-figs. 5–6), a small spherical alveoline showing not more than seven chambers in its final whorl. This species was originally described by Schwager (1883) from the "Charaschaff" north of Dakhla Oasis on the road to Farafra, from a limestone bed overlying the Chalk. This bed, which is separated from the Chalk below by a thin shale bed with "ironstone fossils," is in all probability equivalent to the Maqfi limestone member from which this fossil was collected in the present study. *Alveolina ovulum* Stache was restudied by Reichel (1936); his excellent photomicrograph (1936, p. 87) shows *A. ovulum* Stache associated with other microfossils of typical Paleocene age. The present study corroborates Reichel's conclusion that this species is a primitive Paleocene form of the genus *Alveolina*.

Another distinctive member of the reefal assemblage found in this Paleocene unit is *Operculina libyca* Schwager, which is found from the lower Maqfi limestone member to the top layers of the Esna shale.

Nummulites deserti de la Harpe, *N. fraasi* de la Harpe, and *N. solitarius* de la Harpe, which characterize the Egyptian Landenian, occur in large numbers in the calcareous members of the rocks of this age. These three species were first described from Farafra by de la Harpe (1883), who considered them to be among the most primitive of all *Nummulites*. Davis (1935) and Glaessner (1945) placed *N. deserti* de la Harpe and *N. fraasi* de la Harpe at the base of two lineages in the evolution of *Nummulites*. Schaub (1951) studied the structure of these two primitive *Nummulites* in detail, as well as that of *N. solitarius* de la Harpe.

Nummulites fraasi is a small, involute, depressed form with few whorls, increasing rather rapidly in height. *N. deserti*, on the other hand, is more globular, with a

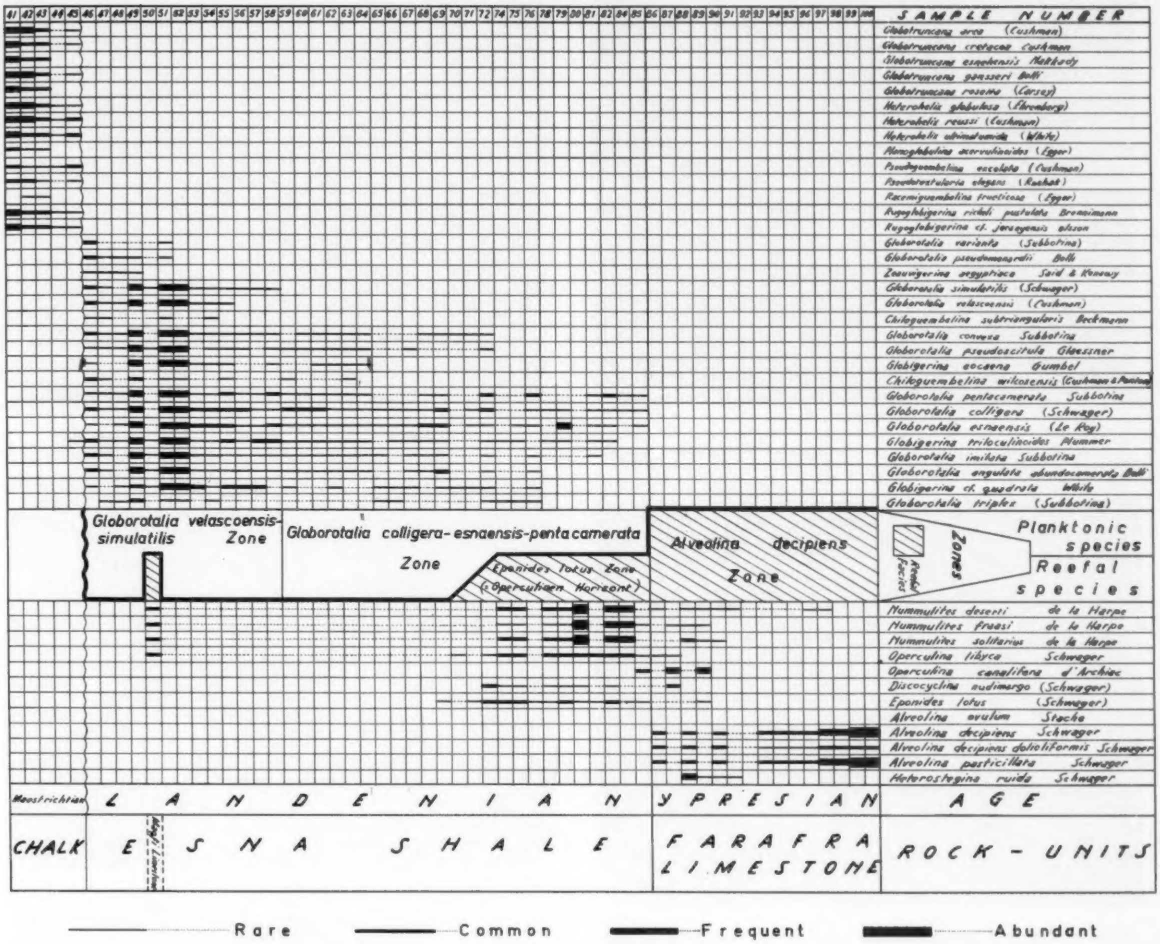


TABLE 1

DISTRIBUTION OF PLANKTONIC AND REEFAL SPECIES RECORDED FROM THE AIN MAQFI SECTION

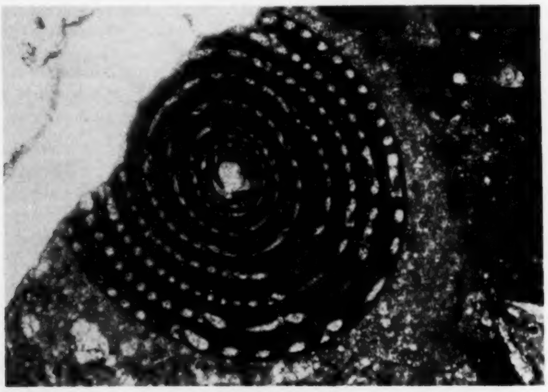
larger number of gradually and slowly increasing whorls, and the septa are quite regular and upright. *N. solitarius* is often confused with *N. deserti*, for they are similar externally. However, *N. deserti* has the whorls increasing more rapidly in height and more strongly curved septa. Text-figure 7 shows diagrammatically the internal structure of these three important species. Although they are primarily of Landenian age, they transcend the upper boundary to appear sporadically in the lower levels of the Ypresian.

The same stratigraphic range is also observed in the case of *Operculina libyca* Schwager (text-fig. 8), a species originally described from this locality but later found to have extensive geographic distribution. The famous *Operculina* limestone was regarded by Hume (1911) and later workers as a marker horizon in the lower levels of the Egyptian Eocene. The presence of *Operculina libyca* Schwager in the Maqfi limestone member and in the upper Esna shale beds, considered to be of Landenian age, alters the known range of this species.

Discocyclina nudimargo (Schwager) has extensive development in the Maqfi limestone member and other calcareous members of the Esna shale Landenian unit. Text-figure 9 is a photomicrograph of sample 80, showing a vertical section of this species and the associated Landenian *Nummulites*. The nucleoconch is bilocular, consisting of a globular chamber partially surrounded by a larger chamber. The equatorial chambers are rectangular, radially elongate, arranged in concentric rings and alternating in position. The lateral chambers have greatly developed pillars, terminating on the surface in poorly developed papillae.

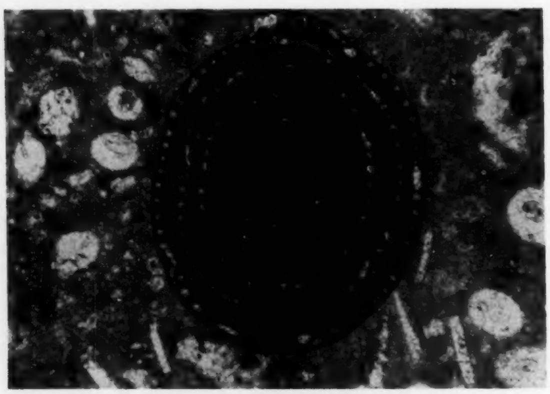
TEXT-FIGURE 4

Nummulites deserti lying next to *Globorotalia simulatilis* (sample 50, Maqfi limestone member), × 48.



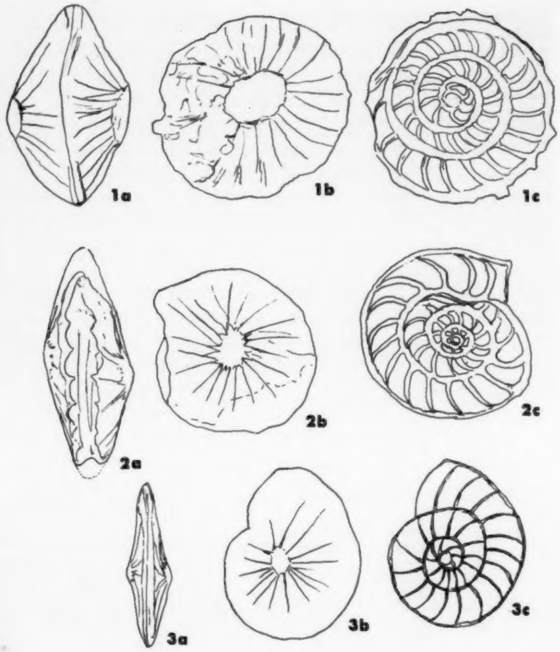
TEXT-FIGURE 5

Axial section of *Alveolina ovulum* (sample 50, Maqfi limestone member), × 48.



TEXT-FIGURE 6

Tangential section of *Alveolina ovulum* (sample 50, Maqfi limestone member), × 48



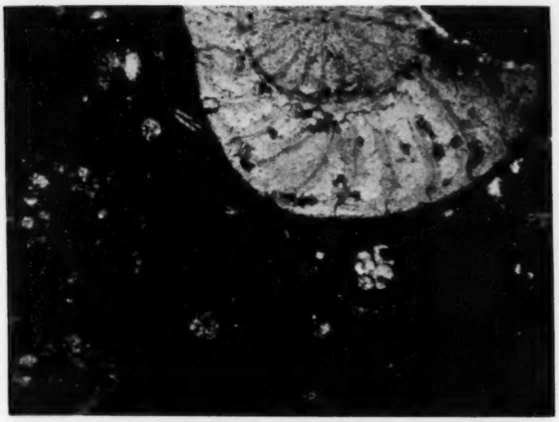
TEXT-FIGURE 7

Diagrammatic sections showing the internal structure (all × 12.5): 1, *Nummulites deserti* (sample 75); 2, *Nummulites solitarius* (sample 79); 3, *Nummulites fraasi* (sample 82); a, side view; b, outer surface; c, equatorial section.

The Farafra limestone foraminifera

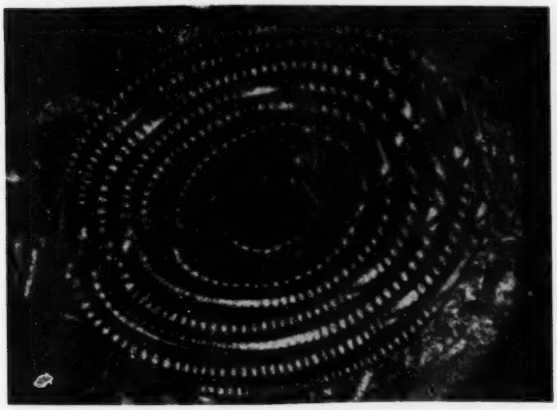
This unit includes the hard beds that can best be studied in thin section. It contains numerous specimens of the family Alveolinidae, together with *Nummulites* species. The latter are particularly common in the lower part of this unit. *Alveolina decipiens* Schwager (text-figs. 10–11) is especially abundant; it is a more or less spherical form, having a flosculinized wall with intensive thickening of the basal layer. The septulae are parallel, straight, and continuous, about 20–24 per millimeter of diameter of the final whorl. The chamberlets are oval to rectangular. The preseptal passage is well developed and large, and the postseptal canal is small and poorly developed.

Alveolina decipiens dolioliformis Schwager (text-fig. 12) is a less common form, characterized by a flosculinized wall and a more crowded earlier spire. *Alveolina pasticillata* Schwager (text-fig. 13) is another Paleocene form that was recorded by Schwager (1883) from the Eastern Desert of Egypt. It is here recorded in large numbers. This flosculinized form differs from *A. decipiens* Schwager in having fewer whorls, in being more cylindrical in shape, and in having more rounded and alternating chamberlets.

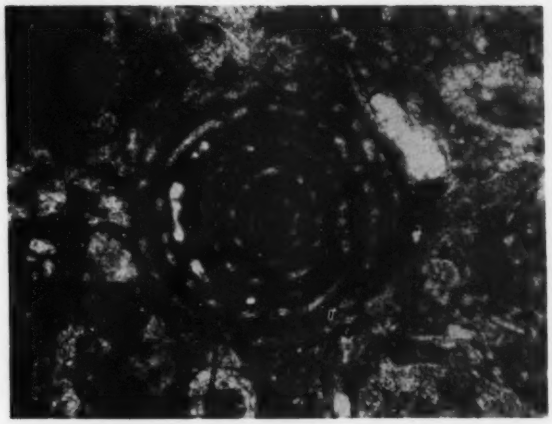


TEXT-FIGURE 8
Operculina libyca (sample 50, Maqfi limestone member), × 40.

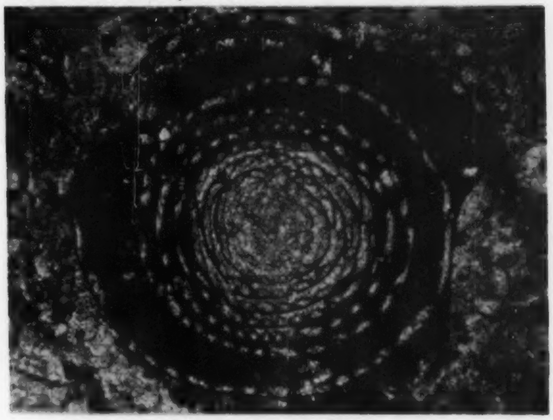
TEXT-FIGURE 9
Thin section × 40, from the upper calcareous shales of the Esna shale (sample 80), showing axial sections of *Nummulites deserti*, *N. fraasi*, and *Discocyclina nudimargo*.



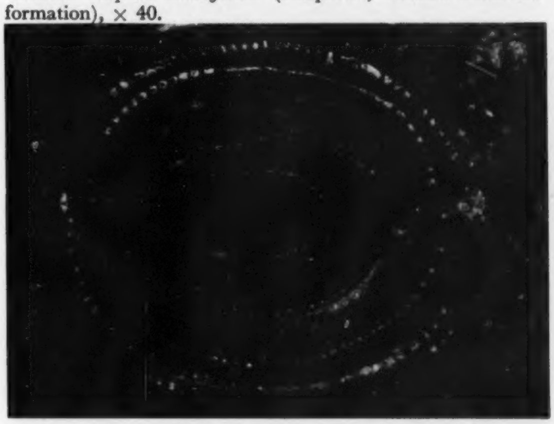
TEXT-FIGURE 10
Axial section of *Alveolina decipiens* (sample 95, Farafra limestone formation), × 40.



TEXT-FIGURE 11
Equatorial section of *Alveolina decipiens* (sample 97, Farafra limestone formation), × 40.



TEXT-FIGURE 12
Alveolina decipiens dolioliformis (sample 97, Farafra limestone formation), × 40.



TEXT-FIGURE 13
Alveolina pasticillata (sample 86, Farafra limestone formation), × 48.

The alveolinid assemblage described from the Farafra limestone unit is unique the world over, and, in the absence of other distinctive microfossils, these forms are taken as markers for the Ypresian age of this unit. The Farafra limestone differs radically in its faunal content and lithology from a supposedly equivalent Ypresian unit (the Thebes formation) that was previously described by the senior author (Said, 1960) from the Nile Valley. The Farafra limestone is regarded as representing the reefal facies of the Egyptian Ypresian. This facies is spotty in its geographic distribution and has recently been interpreted as due to the development of "table reefs" on the submerged highs of the Egyptian Ypresian sea (Said, MS). The fact that Farafra represented an uplifted swell in post-Maestrichtian time, as indicated by the absence of the Danian, supports this hypothesis.

SUMMARY AND CONCLUSIONS

These micropaleontological studies of the Ain Maqfi section, Farafra Oasis, have resulted in a number of interesting conclusions. The detailed study of the planktonic faunas, not previously attempted, has conclusively established the age of the different rock units that make up this section; the Chalk is of Maestrichtian age; the Esna shale is of upper Paleocene (Landenian) age; and the Farafra limestone is of Ypresian age. A definite paleontologic break has been revealed between the Maestrichtian Chalk and the Esna shale, thus ending a controversy that was started in 1883 by Zittel, who considered this locality a place of continuous sedimentation. This break indicates that the Farafra area was a swell in the stable belt of Egypt (Said, MS), which remained above sea level during the Danian and was later flooded by the Ypresian sea, forming a submerged high which favoured the development of a restricted reefal facies in this area.

The Farafra swell, which was uplifted intermittently during upper Paleocene time, offers a perfect section for studying the stratigraphic ranges of several reefal species of *Nummulites* and *Alveolina*, which occur in facies that alternate with beds carrying open-sea planktonic species with well-established ranges. *Nummulites deserti* de la Harpe, *N. fraasi* de la Harpe, *N. solitarius* de la Harpe, *Alveolina ovulum* Stache, and *Discocyclina nudimargo* (Schwager) are thus conclusively shown to be of upper Paleocene age, which corroborates many of the current views on the evolution of these important groups and establishes the ranges of these primitive Egyptian species, whose age has hitherto been considered doubtful.

SYSTEMATIC DESCRIPTIONS

The specimens figured in this study are housed in the Geology Department, Faculty of Science, Cairo University. Other hypotypes have been deposited in the collections of the Department of Micropaleontology, American Museum of Natural History, New York.

Order FORAMINIFERA
Family GLOBOROTALIIDAE Cushman, 1927
Genus GLOBOROTALIA Cushman, 1927

Globorotalia angulata abundocamerata Bolli
Plate 1, figure 13

Globorotalia angulata abundocamerata BOLLI, 1957, U. S. Nat. Mus., Bull. 215, p. 74, pl. 17, figs. 4–6.

Test free, trochospiral; spiral side slightly convex, inner whorl occasionally slightly raised; umbilical side strongly convex; periphery lobate, acute; chambers increasing rather gradually in size as added, slightly imbricating; five chambers in the final whorl.

This subspecies is a multichambered form of *G. angulata* (White), which was recorded by Bolli from the upper Paleocene of Trinidad. In Farafra this form is an important member of the sharp-keeled *Globoratalia* Landenian assemblage; it occurs throughout the Esna shale formation.

Globorotalia esnaensis (LeRoy)
Plate 1, figure 6

Globigerina esnaensis LEROY, 1953, Geol. Soc. Amer., Mem. 54, p. 31, pl. 6, figs. 8–10. – NAKKADY, 1959, Micropaleontology, vol. 5, no. 4, p. 461, pl. 3, fig. 2.
Truncorotalia esnaensis (LeRoy). – SAID AND KENAWY, 1956, Micropaleontology, vol. 2, no. 2, p. 151, pl. 6, fig. 7.
Globorotalia esnaensis (LeRoy). – LOEBLICH AND TAPPAN, 1957, U. S. Nat. Mus., Bull. 215, p. 189, pl. 57, figs. 7a–c(?); pl. 61, figs. 1–2, 9a–c.

Typical specimens of this species, which was originally described from the Farafra area, are found throughout the Esna shale formation. This is a distinct species, associated with the sharp-keeled *Globorotalia* assemblage.

Globorotalia colligera (Schwager)
Plate 1, figure 14

Truncatulina colligera SCHWAGER, 1883, Palaeontographica, vol. 30, pt. 1, p. 126, pl. 29, fig. 14.
Globorotalia simulatilis (Schwager). – NAKKADY, 1959, Micropaleontology, vol. 5, no. 4, p. 462, pl. 4, fig. 2.

Test free, trochospiral, small, inflated; spiral side flattened; umbilical side convex; umbilicus large; periphery lobulate; chambers increasing rapidly in size as added, four in the final whorl, the final chamber occupying more than one-third of the umbilical side; sutures distinct, depressed, radial; wall calcareous, finely perforate; aperture an interiomarginal arch, extra-umbilical in position.

Much confusion has arisen concerning the identity of this species, which was first described by Schwager from Farafra. A study of available topotype material shows that it differs from *G. simulatilis* (Schwager), with which it has been confused, in the rapidly increasing width of its whorls, which is particularly obvious on the spiral side; in having the chambers inflated on the flattened spiral side, each chamber being slightly convex; and in

having a more lobulate periphery. This species occurs throughout the Esna shale formation and forms one of the most important elements of the sharp-keeled *Globorotalia* assemblage.

Globorotalia convexa Subbotina
Plate 1, figure 7

Globorotalia convexa SUBBOTINA, 1953, Trudy Vsesoyuz. Neftyan. Nauchno-Issledovatel. Geol.-Razvedoch. Inst., new ser., no. 76, p. 209, pl. 17, figs. 2–3. – LOEBLICH AND TAPPAN, 1957, U. S. Nat. Mus., Bull. 215, p. 188, pl. 48, fig. 4a–c; pl. 50, fig. 7a–c; pl. 53, figs. 6–8; pl. 57, figs. 5–6; pl. 61, fig. 4a–c; pl. 63, fig. 4a–c.

Test free, circular in outline, low trochospiral, plano-convex; umbilicus small; chambers gradually enlarging, eight in the final whorl; sutures almost flush, strongly curved on the spiral side, radial on the umbilical side; wall calcareous, perforate; surface finely spinose; aperture interiomarginal, extra-umbilical to umbilical, with a narrow lip. This species was found throughout the Esna shale formation of Farafra.

Globorotalia imitata Subbotina
Plate 1, figure 1

Globorotalia imitata SUBBOTINA, 1953, Trudy Vsesoyuz. Neftyan. Nauchno-Issledovatel. Geol.-Razvedoch. Inst., new ser., no. 76, p. 206, pl. 16, figs. 14–16.

Test free, tiny; spiral side flattened; peripheral margin subrounded; peripheral outline slightly lobulate; chambers moderately inflated, ovate, increasing gradually in size as added, in a low trochospiral coil, with five in the final whorl; sutures distinct, slightly depressed, gently curved.

These specimens differ from the typical form in having a more acute peripheral margin. The species differs from *G. pseudoscitula* Glaessner in having a less rounded peripheral outline, a less acute peripheral margin, a less convex spiral side, and a somewhat larger final chamber.

Globorotalia pentacamerata Subbotina
Plate 1, figure 15

Acarinina pentacamerata (Subbotina). – SUBBOTINA, 1953, Trudy Vsesoyuz. Neftyan. Nauchno-Issledovatel. Geol.-Razvedoch. Inst., new ser., vol. 76, p. 233, pl. 23, fig. 8; pl. 24, figs. 1–9.

Typical specimens of this species were found throughout the Esna shale formation in Farafra. This species is characterized by its compressed test, subtruncate periphery, and somewhat spinose surface, and by having five more or less equal chambers in the final whorl.

Globorotalia pseudomenardii Bolli
Plate 1, figure 5

Globorotalia pseudomenardii BOLLI, 1957, U. S. Nat. Mus., Bull. 215, p. 77, pl. 20, figs. 14–17. – LOEBLICH AND TAPPAN, 1957, U. S. Nat. Mus., Bull. 215, p. 193, pl. 45, fig. 10a–c; pl. 47, fig. 4a–c; pl. 49, fig. 6a–c; pl. 54, figs. 10–13; pl. 59, fig. 3a–c; pl. 60, fig. 8a–c; pl. 63, fig. 1a–c. – NAKKADY, 1959, Micropaleontology, vol. 5, no. 4, p. 462, pl. 4, fig. 3.

Globorotalia membranacea (Ehrenberg). – LEROY, 1953 (non SAID AND KENAWY, 1956), Geol. Soc. Amer., Mem. 54, p. 32, pl. 3, figs. 13–14, 41.

Test free, biconvex, compressed, trochospiral; periphery angular; chambers low, broad, and inflated, five visible on the umbilical side, wedge-shaped in outline, the last chamber relatively large; sutures distinct, depressed; wall calcareous, finely perforate, surface smooth; aperture interiomarginal, umbilical to extra-umbilical, with a lip. Specimens were found in the lower part of the Esna shale formation of Farafra.

Globorotalia pseudoscitula Glaessner
Plate 1, figure 2

Globorotalia pseudoscitula GLAESSNER, 1937, Moscow Univ., Lab. Pal., Studies in Micropal., vol. 1, no. 1, pp. 32, 49, text-fig. 3a–c. – LOEBLICH AND TAPPAN, 1957, U. S. Nat. Mus., Bull. 215, p. 193, pl. 46, fig. 4a–c; pl. 48, fig. 3a–c; pl. 53, fig. 5a–c; pl. 59, fig. 2a–c; pl. 63, fig. 6a–c.

Test free, small, trochospiral, biconvex, almost lenticular in form; umbilicus small to nearly closed; peripheral margin acute and slightly keeled; chambers triangular in shape, increasing very gradually in size as added, five in the last whorl; sutures nearly flush, strongly curved on the spiral side, radial on the umbilical side; wall calcareous, finely perforate, surface smooth. This species was found throughout the Esna shale formation of Farafra.

Globorotalia simulatilis (Schwager)
Plate 1, figure 8

Discorbina simulatilis SCHWAGER, 1883 (not LEROY, 1953), Palaeontographica, vol. 30, pt. 1, p. 120, pl. 29(6), fig. 15a–d.

Test free, small, trochospiral, inflated; spiral side slightly convex; umbilicus small; periphery broadly rounded, undulating, and slightly keeled; chambers increasing gradually in size as added, five in the final whorl; sutures distinct, depressed, radial on the umbilical side, strongly curved on the spiral side; wall calcareous, finely perforate, surface smooth; aperture an interiomarginal arch, becoming extra-umbilical.

This species differs from *Globorotalia colligera* (Schwager) in having a slightly convex spiral side, a smaller umbilicus, the chambers increasing gradually in size, and more curved sutures on the spiral side. The final chamber occupies not more than one-fifth of the umbilical side, rather than over one-third of that side as in *G. colligera* (Schwager). It differs from *G. velascoensis* (Cushman) in having a smaller and less well-defined umbilicus and fewer chambers in the final whorl.

This species is common in the lower part of the Esna shale formation. It forms an important member of the sharp-keeled *Globorotalia* assemblage.

Globorotalia triplex (Subbotina)
Plate 1, figure 11

Acarinina triplex SUBBOTINA, 1953, Trudy Vsesoyuz. Neftyan. Nauchno-Issledovatel. Geol.-Razvedoch. Inst., new ser., no. 76, p. 230, pl. 23, figs. 1–5.

Test free, trochospiral; spiral side flattened; umbilicus small; peripheral margin broadly rounded; peripheral outline lobulate; three chambers in the final whorl, increasing rather rapidly in size as added, ovate in shape, sometimes overhanging the preceding suture; sutures depressed; wall calcareous, coarsely perforate; aperture a small interiomarginal arch.

This species was originally described from the Paleocene — lower Eocene of the U.S.S.R. It was found in small numbers throughout the Esna shale formation of Farafra.

Globorotalia varianta (Subbotina)
Plate 1, figure 4

Globigerina varianta SUBBOTINA, 1953, Trudy Vsesoyuz. Neftyan. Nauchno-Issledovatel. Geol.-Razvedoch. Inst., new ser., no. 76, p. 63, pl. 3, figs. 5–12; pl. 4, figs. 1–3; pl. 15, figs. 1–3.
Globorotalia varianta (Subbotina). – LOEBLICH AND TAPPAN, 1957, U. S. Nat. Mus., Bull. 215, p. 196, pl. 44, figs. 1–2; pl. 45, fig. 4a–c.

Test free, small, with a low trochospiral coil; periphery subtruncate; umbilical side with a small and deep umbilicus; chambers globular and inflated, increasing rapidly in size as added, five in the final whorl; sutures distinct, depressed; wall calcareous, finely perforate; aperture extraumbilical-umbilical.

Our specimens are similar to those recorded by Subbotina but differ from those described by Loeblich and Tappan in not being spinose and in having a smaller umbilicus. The latter feature, its small size, and its characteristic appearance in peripheral view distinguish it from *Globigerina pseudobulloides* (Plummer). This species is common in the lower part of the Esna shale formation of Farafra.

Globorotalia velascoensis (Cushman)
Plate 1, figure 10

Pulvinulina velascoensis CUSHMAN, 1925, Cushman Lab. Foram. Res., Contr., vol. 1, pt. 1, p. 19, pl. 3, fig. 5a–c.
Truncorotalia velascoensis (Cushman). – SAID AND KENAWY, 1956, Micropaleontology, vol. 2, no. 2, p. 152, pl. 6, fig. 4.
Globorotalia velascoensis (Cushman). – BOLLI, 1957, U.S. Nat. Mus., Bull. 215, p. 76, pl. 20, figs. 1–4. – LEROY, 1953, Geol. Soc. Amer., Mem. 54, p. 33, pl. 3, figs. 1–3. – NAKKADY, 1959, Micropaleontology, vol. 5, no. 4, p. 462, pl. 4, fig. 4.

This is a distinct species of the sharp-keeled *Globorotalia* groups, characterized by having more than five chambers in the final whorl and a wide and deep umbilicus defined by local umbilical inflation of the chambers. In Farafra this species is common to frequent in the lower part of the Esna shale formation.

Family GLOBOTRUNCANIDAE Brotzen, 1942
Genus RUGOGLOBIGERINA Bronnimann, 1952

Rugoglobigerina reicheli pustulata Bronnimann
Plate 2, figure 8

Rugoglobigerina reicheli pustulata BRONNIMANN, 1952, Bull. Amer. Pal., vol. 34, no. 140, p. 20, pl. 2, figs. 6–7. – OLSSON, 1960, Jour. Pal., vol. 34, no. 1, p. 50, pl. 10, figs. 13–15.

Test trochospiral, biconvex; spiral side slightly depressed; chambers ovate, five or six in the final whorl; periphery rounded.

This species differs from *R. jerseyensis* Olsson in having a more flattened spiral side and more chambers in the final whorl. It was originally described from the Maestrichtian of Trinidad and has been recorded from the New Jersey coastal plain. It is common in all the Chalk samples from Farafra.

Rugoglobigerina sp. cf. **R. jerseyensis** Olsson
Plate 2, figure 7

Rugoglobigerina jerseyensis OLSSON, 1960, Jour. Pal., vol. 34, no. 1, p. 49, pl. 10, figs. 19–21.

Test low trochospiral, compressed; periphery lobate; wall smooth; chambers ovate, five in the final whorl; sutures slightly curved, depressed; umbilicus small, shallow; aperture interiomarginal, umbilical, covered by tegilla which extend over the umbilicus, with accessory apertures.

Our specimens differ from the typical form in having the wall smooth rather than spinose, but they closely resemble Olsson's species recorded from the New Jersey coastal plain in other details. This species was found commonly in the Maestrichtian Chalk of Farafra.

Genus GLOBOTRUNCANA Cushman, 1927

Globotruncana arca (Cushman)
Plate 2, figure 14

Pulvinulina arca CUSHMAN, 1926, Cushman Lab. Foram. Res., Contr., vol. 2, pt. 1, p. 23, pl. 3, fig. 1a–c.
Globotruncana arca (Cushman). – CUSHMAN, 1946, U. S. Geol. Survey, Prof. Paper 206, p. 150, pl. 62, figs. 4–5.

A large number of specimens of this species were found in all the Chalk samples examined from Farafra.

Globotruncana cretacea Cushman
Plate 2, figure 10

Globotruncana cretacea CUSHMAN, 1946, U. S. Geol. Survey, Prof. Paper 206, p. 150, pl. 62, fig. 7. – NAKKADY AND OSMAN, 1954, Congr. Geol. Internat. (Algiers, 1952), C. R., sec. 13, p. 79, pl. 19, fig. 10.

Test biconvex; periphery single-keeled, lobulate; chambers distinct, the last chamber semicircular in outline and exceptionally large; sutures distinct, dorsally strongly curved and beaded, ventrally slightly depressed; umbilicus small, with marginal flaps; aperture interiomarginal.

This species, known from the Upper Cretaceous of the U.S. Gulf Coast, was found commonly in the Chalk samples from the section studied. It was previously recorded from Sinai by Nakkady and Osman (1954).

Globotruncana esnehensis Nakkady
Plate 2, figure 12

Globotruncana arca (Cushman) var. *esnehensis* NAKKADY, 1950, Jour. Pal., vol. 24, p. 690, pl. 90, figs. 23–26.
Globotruncana esnehensis Nakkady. – NAKKADY AND OSMAN, 1954, Congr. Geol. Internat. (Algiers, 1952), C.R., sec. 13, p. 79, pl. 19, fig. 3a–c. – SAID AND KENAWY, 1956, Micropaleontology vol. 2, no. 2, p. 150, pl. 5, fig. 21.

Test trochospiral, spiroconvex, the spiral side made up of two whorls; chambers distinct, five or six in the final whorl; umbilicus deep; sutures strongly curved, beaded dorsally, slightly curved and depressed ventrally; aperture interiomarginal, with perforated tegilla.

This species differs from *G. calciformis* in being less markedly spiroconvex and in having two whorls on the spiral side. This is a common Upper Cretaceous species, which has been recorded from various parts of Egypt. A large number of specimens was found in all Chalk samples of the material examined.

Globotruncana gansseri Bolli
Plate 2, figure 16

Globotruncana gansseri BOLLI, 1951, Jour. Pal., vol. 25, p. 196, pl. 35, figs. 1–3. – SAID AND KENAWY, 1956, Micropaleontology, vol. 2, no. 2, p. 150, pl. 5, fig. 17.

Test trochospiral, umbilicoconvex, marginally keeled; chambers inflated, five or six in the last whorl; sutures dorsally curved and limbate, ventrally slightly curved and depressed; umbilicus deep; aperture with perforate tegilla, interiomarginal, umbilical.

A lage number of specimens of this Maestrichtian index fossil, first recorded from Trinidad, were found in the Chalk samples of Farafra. At Dakhla Oasis to the south (Said, MS), this species, as in Trinidad (Bolli, 1951), characterizes the lower levels of the Maestrichtian. The presence of this species in Farafra in the uppermost Maestrichtian beds may indicate that part of the Maestrichtian is missing owing to erosion or nondeposition.

Globotruncana rosetta (Carsey)
Plate 2, figure 13

Globigerina rosetta CARSEY, 1926, Texas Univ. Bull. 2612, p. 44, pl. 5, fig. 3a–c
Globotruncana rosetta (Carsey). – BANDY, 1951, Jour. Pal., vol. 25, no. 4, p. 509, pl. 75, fig. 4a–c. – NAKKADY AND OSMAN, 1954, Congr. Geol. Internat. (Algiers, 1952), C. R., sec. 13, p. 84, pl. 19, fig. 7a–c.

Test trochospiral, umbilicoconvex to biconvex; umbilicus large; periphery lobate, single-keeled; chambers six in the final whorl; sutures dorsally limbate, beaded, and oblique, ventrally very slightly curved and radial; aperture interiomarginal, with marginal flaps. A large number of specimens of this species were found in the Chalk samples of Farafra. This species is known from the Upper Cretaceous of the U.S. West Coast and Gulf Coast, Mexico, and Trinidad. It was previously recorded by Nakkady and Osman from Sinai.

Family HETEROHELICIDAE Cushman, 1927
Genus CHILOGUEMBELINA Loeblich and Tappan, 1956

Chiloguembelina subtriangularis Beckmann
Plate 2, figure 6

Chiloguembelina subtriangularis BECKMANN, 1957, U. S. Nat. Mus., Bull. 215, p. 91, pl. 21, fig. 5; text-fig. 15 (39–42).

Our specimens closely resemble those described by Beckmann from the upper Paleocene (Lizard Springs formation) of Trinidad. They were found in the same stratigraphic horizon in Farafra (lower part of the Esna shale).

Chiloguembelina wilcoxensis (Cushman and Ponton)
Plate 2, figure 4

Guembelina wilcoxensis CUSHMAN AND PONTON, 1932, Cushman Lab. Foram. Res., Contr., vol. 8, p. 66, pl. 8, figs. 16–17. – TOULMIN, 1941, Jour. Pal., vol. 15, p. 597, pl. 80, fig. 24. – BECKMANN, 1957, U. S. Nat. Mus., Bull. 215, p. 92, pl. 21, figs. 10, 12–13; text-fig. 15 (49–58).

This is a distinct species with globular chambers and a symmetrical semicircular aperture. It was found in the lower Esna shale formation of Farafra, associated with *Globorotalia pseudomenardii* Bolli. The stratigraphic range and associations of *Chiloguembelina wilcoxensis* in Farafra are therefore similar to those in the Lizard Springs formation of Trinidad.

Genus ZEAUVIGERINA Finlay, 1939

Zeauvigerina aegyptiaca Said and Kenawy
Plate 2, figure 5

Zeauvigerina aegytiaca SAID AND KENAWY, 1956, Micropaleontology, vol. 2, no. 2, p. 141, pl. 4, fig. 1. – BECKMANN, 1957, U. S. Nat. Mus., Bull. 215, p. 92, pl. 21, figs. 9–11; text-fig. 15 (59–62).

The specimens from Farafra are similar in detail and in stratigraphic range to those described from Sinai and from Trinidad. This species seems to be an index fossil for the Landenian.

Subfamily HETEROHELICINAE Cushman, 1927
Genus HETEROHELIX Ehrenberg, 1841

Heterohelix globulosa (Ehrenberg)
Plate 2, figure 1

Guembelina globulosa (Ehrenberg). – CUSHMAN, 1946, U. S. Geol. Survey, Prof. Paper 206, p. 105, pl. 45, figs. 9–15. – SAID AND KENAWY, 1956, Micropaleontology, vol. 2, no. 2, p. 139, pl. 3, fig. 29.

This well-known species was found in large numbers in the Chalk samples of Farafra. It is characterized by a pair of large, rather inflated final chambers. The initial part of the test is usually depressed, with the chambers increasing but little as added.

Heterohelix reussi (Cushman)
Plate 2, figure 3

Guembelina reussi Cushman. – CUSHMAN, 1946, U. S. Geol. Survey, Prof. Paper 206, p. 104, pl. 44, figs. 18–19. – LEROY, 1953, Geol. Soc. Amer., Mem. 54, p. 34, pl. 8, fig. 14. – SAID AND KENAWY, 1956, Micropaleontology, vol. 2, no. 2, p. 139, pl. 3, fig. 32.

This species is characterized by its tapering test and the gradual rapid increase in size of the chambers as added. It closely resembles *H. globulosa* (Ehrenberg) except for the tendency of the earlier chambers to be distinct and clearly set off from one another. It was found in large numbers in all the Chalk samples of Farafra.

Heterohelix ultimatumida (White)
Plate 2, figure 2

Guembelina ultimatumida WHITE, 1929, Jour. Pal., vol. 3, p. 39, pl. 4, fig. 13. – CUSHMAN, 1946, U. S. Geol. Survey, Prof. Paper 206, p. 107, pl. 46, figs. 6–7. – SAID AND KENAWY, 1956, Micropaleontology, vol. 2, no. 2, p. 139, pl. 3, fig. 31.

This species is characterized by having the early portion rapidly tapering and the later portion increasing but little in width. The periphery is slightly indented, and the chambers are inflated. It was found in large numbers in the Chalk samples of Farafra.

Genus PSEUDOTEXTULARIA Rzehak, 1891

Pseudotextularia elegans (Rzehak)
Plate 2, figure 9

Guembelina plummerae Loetterle. – CUSHMAN, 1946, U. S. Geol. Survey, Prof. Paper 206, p. 104, pl. 45, figs. 1–3. – SAID AND KENAWY, 1956, Micropaleontology, vol. 2, no. 2, p. 139, pl. 3, fig. 33.
Pseudotextularia elegans (Rzehak). – GALLITELLI, 1957, U. S. Nat. Mus., Bull. 215, p. 138, pl. 33, fig. 6. – OLSSON, 1960, Jour. Pal., vol. 34, no. 1, p. 28, pl. 4, figs. 9–10.

Test tapering throughout; chambers of the later portion strongly inflated, occasionally with one or more irregularly placed chambers at the upper end; sutures depressed; wall distinctly costate; aperture a low broad arch with a slight lip. This widely distributed species has been recorded from Upper Cretaceous rocks in many parts of the world.

Genus PSEUDOGUEMBELINA Bronnimann and Brown, 1953

Pseudoguembelina excolata (Cushman)
Plate 2, figure 11

Pseudoguembelina excolata (Cushman). – BRONNIMANN AND BROWN, 1953, Cushman Found. Foram. Res., Contr., vol. 4, p. 153, text-figs. 1–4. – SAID AND KENAWY, 1956, Micropaleontology, vol. 2, no. 2, p. 139, pl. 3, fig. 36. – OLSSON, 1960, Jour. Pal., vol. 34, no. 1, p. 28, pl. 4, fig. 11.

Typical specimens of this widely distributed Upper Cretaceous species were found commonly in the Chalk samples of Farafra.

PLATE 1

All figures × 50

1 *Globorotalia imitata* Subbotina
Sample 51.

2 *Globorotalia pseudoscitula* Glaessner
Sample 46.

3 *Globigerina eocaena* Gümbel
Sample 46.

4 *Globorotalia varianta* (Subbotina)
Sample 46.

5 *Globorotalia pseudomenardii* Bolli
Sample 46.

6 *Globorotalia esnaensis* (LeRoy)
Sample 49.

7 *Globorotalia convexa* Subbotina
Sample 46.

8 *Globorotalia simulatilis* (Schwager)
Sample 46.

9 *Globigerina triloculinoides* Plummer
Sample 46.

10 *Globorotalia velascoensis* (Cushman)
Sample 49.

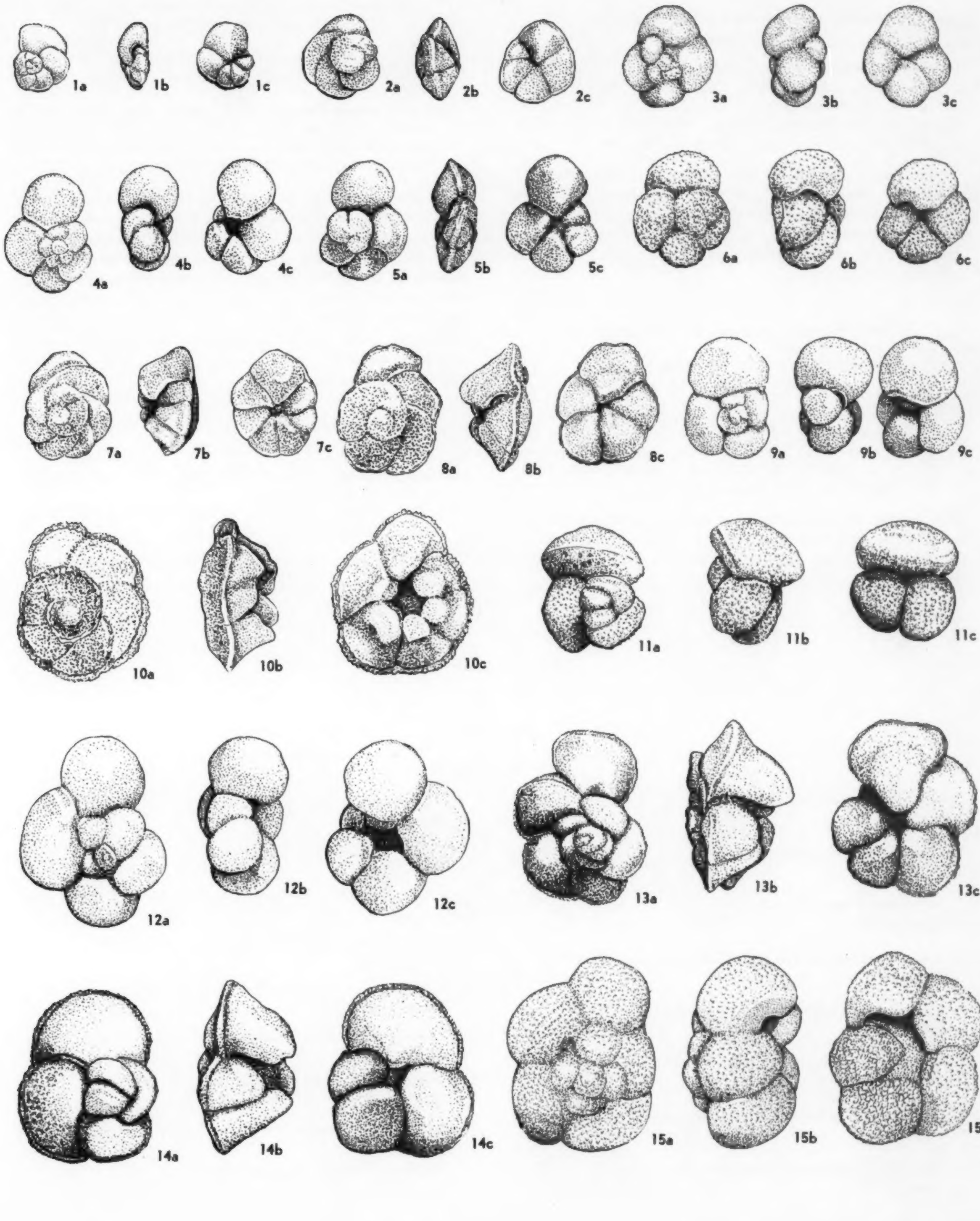
11 *Globorotalia triplex* (Subbotina)
Sample 52.

12 *Globigerina* sp. cf. *G. quadrata* White
Sample 53.

13 *Globorotalia angulata abundocamerata* Bolli
Sample 52.

14 *Globorotalia colligera* (Schwager)
Sample 49.

15 *Globorotalia pentacamerata* Subbotina
Sample 54.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Genus RACEMIGUEMBELINA Gallitelli, 1957

Racemiguembelina fructicosa (Egger)
Plate 2, figure 17

Guembelina fructicosa EGGER, 1900, K. bayer. Akad. Wiss. München, Math-naturh. Abt., Abh., Kl. 2, vol. 21, p. 35, pl. 14, figs. 8–9.
Racemiguembelina fructicosa (Egger). – GALLITELLI, 1957, U. S. Nat. Mus., Bull. 215, p. 142, pl. 32, figs. 14–15.

Test conical, biserial in the beginning, increasing regularly in thickness and breadth, and finally showing chamber proliferation in the form of a crown. This species, known from the Upper Cretaceous of Europe and the U.S., was found in small numbers in the Chalk samples of Farafra.

Genus PLANOGLOBULINA Cushman, 1927

Planoglobulina acervulinoides (Egger)
Plate 2, figure 15

Planoglobulina acervulinoides (Egger). – CUSHMAN, 1946, U. S. Geol. Survey, Prof. Paper 206, p. 111, pl. 47, figs. 12–15. – SAID AND KENAWY, 1956, Micropaleontology, vol. 2, no. 2, p. 140, pl. 3, fig. 45. – OLSSON, 1960, Jour. Pal., vol. 34, no. 1, p. 28, pl. 4, fig. 12.

This widely distributed species has been recorded from the U.S. Gulf Coast and Atlantic coastal plain, from Mexico, and from Sinai. It was found rarely in the Chalk samples of Farafra.

Family ORBULINIDAE Schultze, 1954
Subfamily GLOBIGERININAE Carpenter, 1826
Genus GLOBIGERINA d'Orbigny, 1826

Globigerina eocaena Gümbel
Plate 1, figure 3

Globigerina eocaena GÜMBEL, 1870, Akad., Wiss., Abh., vol. 10, p. 662, pl. 2, fig. 109. – SUBBOTINA, 1953, Trudy Vsesoyuz. Neftyan. Nauchno-Issledovatel. Geol.-Razvedoch. Inst., new ser., no. 76, p. 70, pl. 6, fig. 5; pl. 7, fig. 1.

Test free, composed of gradually enlarging chambers in a low trochospiral arrangement; chambers subglobular; the two whorls of chambers visible on the flattened dorsal side, four to four and one-half chambers of the final whorl visible on the umbilical side, all more or less the same in size; sutures distinct depressed; wall calcareous, finely perforate, surface pitted; aperture interiomarginal, umbilical, with a lip. Our specimens resemble those recorded by Bolli (1957*b*, p. 73, pl. 17, figs. 22–24) as *Globorotalia quadrata* (White).

Globigerina sp. cf. **G. quadrata** White
Plate 1, figure 12

Globigerina quadrata WHITE, 1928, Jour. Pal., vol. 2, no. 3, p. 195, pl. 27, fig. 18a–b.
Globorotalia quadrata (White). – BOLLI, 1957, U. S. Nat. Mus., Bull. 215, p. 73, pl. 17, figs. 22–24.

Test low trochospiral, planoconvex; peripheral margin lobate, rounded; wall calcareous, perforate, surface

PLATE 2

All figures × 50

1 *Heterohelix globulosa* (Ehrenberg)
Sample 42.

2 *Heterohelix ultimatumida* (White)
Sample 41.

3 *Heterohelix reussi* (Cushman)
Sample 41.

4 *Chiloguembelina wilcoxensis* (Cushman and Ponton)
Sample 52.

5 *Zeauvigerina aegyptiaca* Said and Kenawy
Sample 46.

6 *Chiloguembelina subtriangularis* Beckmann
Sample 46.

7 *Rugoglobigerina* sp. cf. *R. jerseyensis* Olsson
Sample 41.

8 *Rugoglobigerina reicheli pustulata* Bronnimann
Sample 41.

9 *Pseudotextularia elegans* (Rzehak)
Sample 41.

10 *Globotruncana cretacea* Cushman
Sample 41.

11 *Pseudoguembelina excolata* (Cushman)
Sample 42.

12 *Globotruncana esnehensis* Nakkady
Sample 42.

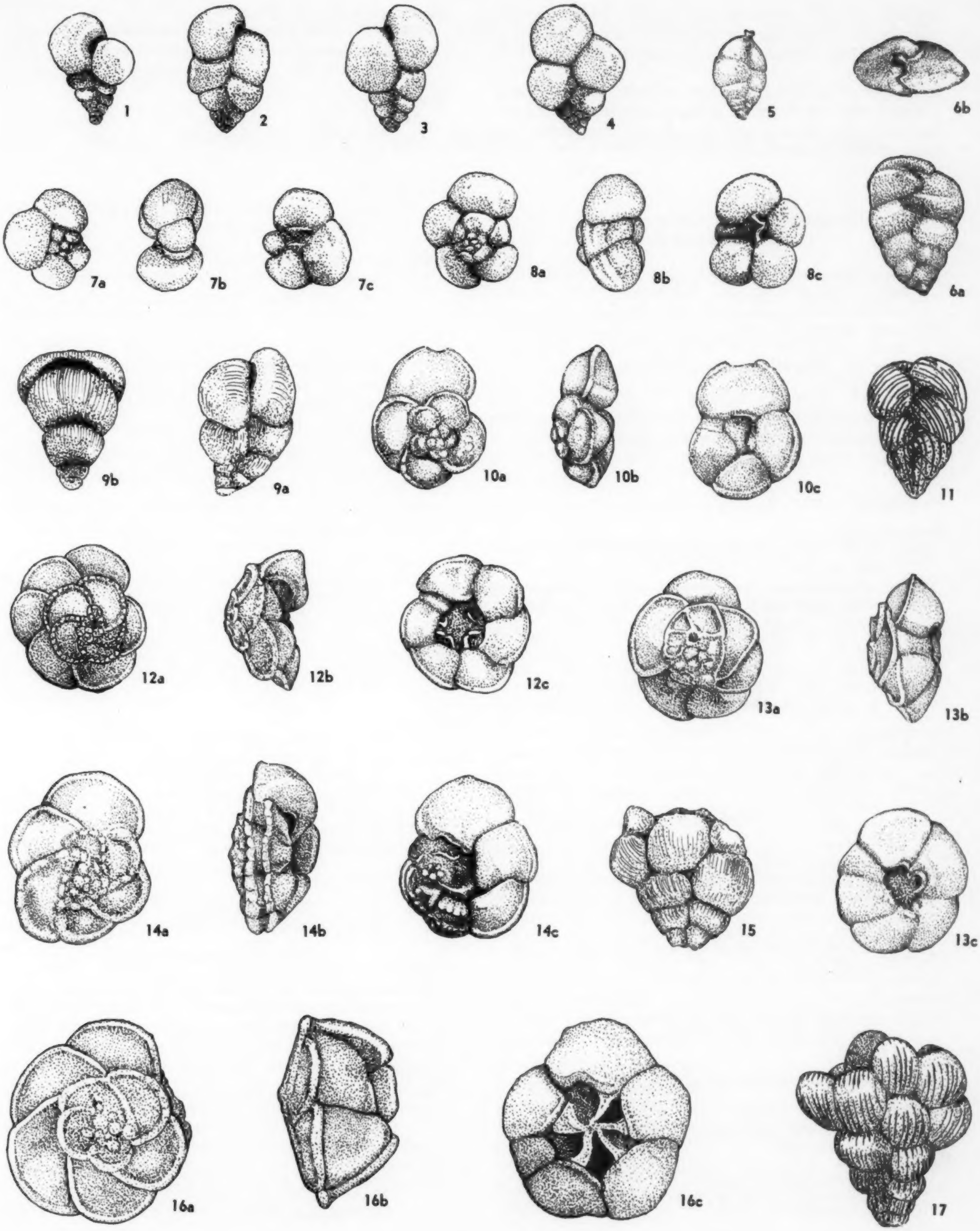
13 *Globotruncana rosetta* (Carsey)
Sample 43.

14 *Globotruncana arca* (Cushman)
Sample 41.

15 *Planoglobulina acervulinoides* (Egger)
Sample 41.

16 *Globotruncana gansseri* Bolli
Sample 42.

17 *Racemiguembelina fructicosa* (Egger)
Sample 42.


1
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10c
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12a
12b
12c
13a
13b
14a
14b
14c
15
13c
16a
16b
16c
17

smooth; chambers inflated, arranged in three volutions dorsally, the four chambers of the last whorl appearing on the umbilical side; umbilicus fairly small.

This species differs from that recorded by Nakkady (1959, p. 461, pl. 3, fig. 3) in being smaller and in having a less pitted surface. It was found throughout the Esna shale formation of Farafra.

Globigerina triloculinoides Plummer
Plate 1, figure 9

Globigerina triloculinoides PLUMMER, 1927, Texas Univ., Bull. 2644, p. 134, pl. 8, fig. 10. – NAKKADY, 1959, Micropaleontology, vol. 5, no. 4, p. 461, pl. 3, fig. 5.
Globigerina pseudotriloba White. – LEROY, 1953, Geol. Soc. Amer., Mem. 54, p. 31, pl. 9, fig. 27. – SAID AND KENAWY, 1956, Micropaleontology, vol. 2, no. 2, p. 157, pl. 7, fig. 25.

Typical specimens of this distinct species were found throughout the Esna shale formation of Farafra.

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ABSTRACT

Some doubtful foraminiferal "brown bodies" in Bryozoa, "egglike" microfossils, dinoflagellates, hystrichospherids, Radiolaria, echinoderm sclerites, scolecodont assemblages, and miscellaneous Problematica in Baltic Cretaceous flintstones are described, with taxonomic comments.

New microfossils from Baltic Cretaceous flintstones

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PRIMITIVE OR DOUBTFUL FORAMINIFERA

The Baltic Cretaceous flintstones frequently contain many foraminifera of different species, but sometimes only a single specimen of a rare species is found during the examination of numerous samples of flint chips, and its preservation is generally too poor to permit exact determination of the species, genus, or even family. The following examples illustrate the occurrence of somewhat primitive or doubtful foraminifera, supplementing my earlier reports on these objects.

SUPPOSED FORAMINIFERA
Family REOPHACIDAE?
Gen. et sp. indet.
Plate 1, figures 1–2

Brown membranous bodies, increasing in size, compose the chamber molds in a more or less closed row. See O. Wetzel (1953*b*, pl. 83, figs. 1–2) for similar fossils, illustrated less clearly.

Subfamily RHIZAMMININAE?
Gen. et sp. indet.
Plate 1, figure 5

A brown membranous branching tube bears a pair of round dark bodies, supposed molds of two chambers, which still retain some shreds of their covering. See O. Wetzel (1953*b*, pl. 83, figs. 3–4).

DOUBTFUL FORAMINIFERA
Genus CHITINODENDRON Eisenack, 1937

Chitinodendron spp. indet.
Plate 1, figures 3–4

Filament-bearing blastulae, dark brown; apparently compressed hollow "chitinous" membranes. They were at first interpreted by the author as "horny" (keratinous) Bryozoa (e.g., *Hippothoa* sp.?) or hydrozoan polyps (see O. Wetzel, 1933, pl. 1, figs. 7–10; 1953*b*, pl. 83, fig. 7). On the other hand, they resemble the Silurian species of *Chitinodendron* established by Eisenack in 1937 and classified doubtfully as foraminifera. More recently, Sigal (in Piveteau, 1952, p. 152) mentioned such primitive tests, i.e., a Cambrian *Chitinodendron* species, in discussing the ancestry of the foraminifera.

SYSTEMATIC POSITION OF PSEUDASTRORHIZULA

MICROFOSSILS INCERTAE SEDIS

Genus **Pseudastrorhizula** O. Wetzel, 1940

Description (based on the 1940 diagnosis): Somewhat starlike round bodies with several more or less thick branches extending nearly radially from an indistinct central region. Color yellowish brown, often darker at the center.

Type species: Pseudastrorhizula eisenacki O. Wetzel, 1940.

Pseudastrorhizula eisenacki O. Wetzel
Plate 1, figures 6–7

Pseudastrorhizula eisenacki O. WETZEL, 1940, Zeitschr. Geschiebf., vol. 16, no. 2, p. 122, pl. 1, figs. 3–4.

Holotype: Collection of O. Wetzel, Eutin; slide no. A 1022 (pl. 1, fig. 6).

Paratype (typoid): Same collection; slide no. A 2160 (pl. 1, fig. 7).

Age and occurrence: Sporadic in Baltic Cretaceous flintstones; found mostly in an isolated condition, but recently within the chambers of fragments apparently belonging to the skeletons of bryozoan colonies.

Description: See that of the genus.

Dimensions: Diameter about 120–160μ.

Comments: My original classification of these flintstone microfossils as foraminifera was intended only as provisional but was justified by their external form, which is obviously similar to *Pseudastrorhiza silurica* Eisenack (1932, p. 259, pl. 11, figs. 1–6). They also resemble *Astrorhiza* Sandahl of Issler (1908, p. 39, pl. 1, figs. 1–3), and Perruche (1936, pp. 23–25, pl. 1, figs. 4–5) recorded a Jurassic form found by him as an internal mold of a foraminifera, probably of the Astrorhizidae.

However, in a later publication (O. Wetzel, 1950, p. 166), I emphasized the fact that some features of the so-called "brown bodies" occurring in fossil Bryozoa seem to coincide with those of *Pseudastrorhizula eisenacki* (compare pl. 1, figs. 8–10, especially the central part of fig. 8). The chemical substance of these "ovoid bodies" (also somewhat problematical) is similar, but *Pseudastrorhizula* has a more hyaline surface, without the

concentric pile lines that are often visible in the "ovoids" (now called "brown bodies"). Because of these two differences, *Pseudastrorhizula eisenacki* may perhaps be regarded as only morphologically convergent with the "brown bodies," having descended from another organism, which is assumed to have been some symbiont of the Bryozoa.

In any case, it seems improbable, in spite of a certain morphological resemblance, that *Pseudastrorhizula eisenacki* has any real affinity with the "euasters," i.e., calcified spicules of Silicispongia described by M. Deflandre-Rigaud (1949, p. 159, text-figs. 22–26). On the whole, the systematic position of *Pseudastrorhizula* is still uncertain, and for the moment these problematic objects should not be included among the foraminifera.

"EGGLIKE" MICROFOSSILS OF UNCERTAIN SYSTEMATIC POSITION

This category includes rare microfossil types of rather ambiguous form, having the general appearance of a very small egg or an aggregate of such bodies.

Microfossils Incertae Sedis

Genus **Palambages** O. Wetzel, **new genus**

"Mor ulosae" O. Wetzel, 1933, Palaeontographica, vol. 78 pp. 23–24.

Derivatio nominis: Lat. *ambages* = uncertainty in two different directions.

Description (based on O. Wetzel, 1933): Spheroidal bodies, composed of many (8–18?) oval membranous cells, sometimes with a flat peripheral portion (with aperture?).

Type species: Palambages morulosa O. Wetzel, 1961.

Palambages morulosa O. Wetzel, **new species**
Plate 1, figure 11

"Moruloase" O. Wetzel, 1933, Palaeontographica, vol. 78, pp. 23–24, pl. 4, figs. 1–5.

Derivatio nominis: Lat. *morula* = diminutive of *morum*, a mulberry.

Holotype: Collection of O. Wetzel, Eutin; slide no. A 350 (pl. 1, fig. 11).

Paratypes (typoids): Same collection; slide nos. A 173/509 (figured in 1933).

Age and occurrence: Sporadic in Baltic Cretaceous flintstones, and frequent in the Baltic Senonian and Danian chalk and flint, in place.

Description: See that of the genus.

Dimensions: Assemblages about 80–120μ; single cells about 30–50μ in diameter.

Comments: These microfossils are identical with the objects recorded previously as "Morulosae" (O. Wetzel, 1933, pp. 23–24, pl. 4, figs. 1–5). A detailed discussion of their possible systematic relations with extant microorganisms was given in that paper. From a purely morphologic point of view, they stand between the egg-balls of planktonic crustaceans (e.g., those of *Clausocalanus*) and the coenobia of the alga *Coelastrum.* Perhaps these fossil forms may be provisionally classified in the form-group Hystrichosphaeridea s.l. In any case, to conform to correct taxonomic procedure, I have here assigned them Linnean nomenclature in place of the group name "Morulosae" O. Wetzel (1933).

Remark: There are, perhaps, other smaller species with fewer cells; an aberrant form, not certainly known, was reported by the author (O. Wetzel, 1953*a*, p. 41, pl. 2, fig. 11).

Form genus **Palaeobion** O. Wetzel, **new genus**

Description: Spiny spheroidal microfossils, somewhat resembling normal fossil hystrichospherids, as well as some of the extant planktonic "cysts" or eggs described by H. Lohmann (1904).

Type species: Palaeobion catenatum O. Wetzel, 1961.

Palaeobion catenatum O. Wetzel, **new species**
Plate 1, figures 12–13

Holotype: Collection of O. Wetzel, Eutin; slide no. Jt. 75a (pl. 1, figs. 12–13).

Age and occurrence: Found once, in a Cretaceous flintstone from Moens Klint, Denmark.

Description: Spheroidal bodies of brown color. Their relatively thick covering bears sparse, small, conical spines, a few of which are somewhat curved, obliquely arranged, or indistinctly formed. The shells are filled with a pyritized granular substance. The individuals are closely united in a double chain. At the points of contact they have a discoidal surface always bearing short, peg-shaped protuberances. Note the point of breakage at the top of figures 12–13.

Dimensions: Illustrated fragment, 450 × 160μ; single cells 80–85μ in diameter.

Comments: This microfossil, remarkable for the unusual arrangement of egglike bodies, has its counterparts among the extant marine plankton, e.g., *Ovum hispidum capense* H. Lohmann (1904, p. 30, pl. 4, fig. 5, 5a). However, the fossil cells have a thicker cover and not so many or such distinct spines. The fact that no trace of either the mucous envelope or the tubiform membrane that holds the long double chains of living "*Ova hispida*" together is visible in the surrounding flintstone is perhaps not surprising in the case of a fossil body. In any case, it seems more likely that this fossil belongs to the "*Ova hispida*" than to the ordinary hystrichospheres, which are more membranous. In fact, it appears to be identical with one of the planktonic types which Lohmann distinguished separately, a spiny spheroid with a thick shell and many compact spines (total diameter variable, about 15–45μ). That body, found only in an isolated state in the ocean, was regarded as an indepen-

dent organism *incertae sedis* and therefore designated as "*Bion multispinosum* (Moebius) Lohmann." I have derived the name for the form-genus of my new fossil in accordance with this nomenclature.

Eisenack was in a comparable position with regard to the taxonomy of the Silurian "cysts" before the morphologic group Hystrichosphaeridea was introduced. I hesitate to say, even provisionally, that my unusual but interesting microfossil, found only once as an assemblage, is really a representative of the Hysrichosphaeridea worthy of recognition.

Remark: The object illustrated in figures 12–13 is only a fragment of the original assemblage of 15–16 cells; the flint chip must be cut into smaller pieces for good observation.

Genus **Pleurozonaria** O. Wetzel, 1933

Description (based on the 1933 diagnosis): Spheroidal body of light brown color. Wall thick but perforated by numerous channels, which are generally first apparent under the microscope in the transparent "border."

Type species: Pleurozonaria globulus O. Wetzel, 1933.

Pleurozonaria globulus O. Wetzel
Plate 1, figures 14–15

Holotype: Collection of O. Wetzel, Eutin; slide no. A 405 (pl. 1, figs. 14–15).

Age and occurrence: One specimen in a glacial erratic flintstone of probable Cretaceous (or Jurassic?) age at Krywonogi, Poland.

Description: According to the optical plane of observation, the bright "ribbed border" of the wall is first seen, then (on the "disc" inside the "border") portions of oblique punctate lines, and finally a layer of pores are seen from above. Some of the lines seem (at least in the present state of my single object) to converge in two flattened polar points; the whole body has the appearance of a small globe with meridional lines.

Dimensions: Diameter (total) 40–48μ; "border" (wall) thickness 5–6μ.

Comments: This fossil was previously described in the author's first detailed discussion of the Hystrichosphaeridea (1933, p. 29, pl. 4, fig. 12), where it was distinguished from his species of *Cymatiosphaera*. Recently Eisenack (1957) denoted a thick-walled species of the latter as *Cymatiosphaera pachytheca*, regarding it as related to his species of *Tasmanites*, *Tytthodiscus*, and *Leiosphaeridia*. He combined all these "micromorphs" in the Hystrichosphaeridea, since Sommer (1956) had introduced the new family Tasmanaceae (Algae) for the Paleozoic species of *Tasmanites*. It is undoubtedly possible that these microfossils, striking in their very thick perforated walls, are closely affiliated with each other; at least, it should not be too difficult to establish a common generic name for the forms called *Tasmanites* Newton, 1875 (or Sommer, 1956), *Pleurozonaria* O. Wetzel, 1933, and *Tytthodiscus* Norem, 1955, with more or less slight differences between their species. But even if this is true, what were these microfossils during their lifetime – Algae, Protozoa, spores, or eggs? According to the most recent studies, they represent "crustacean eggs" (Bitterli, 1960, pp. 42, 45) or, at any rate, animal bodies, since they show strong luminescence under ultraviolet light (W. Wetzel, 1959, pp. 264–265, pl. 24, figs. 1–3; Maier, 1959, pp. 298–299).

INTERMEDIATE TRIPARTITE MICROFOSSILS

The Hystrichosphaeridea undoubtedly represent a morphological grouping of very different forms. Besides those resembling plants such as Algae and spores, many others show morphological resemblances to Protista. These forms are of major importance because of the possibility of their relationship to the Radiolaria and, perhaps even more, to the Dinoflagellata. The following examples illustrate some of the microfossils that are intermediate between the Hystrichosphaeridea and the Dinoflagellata, having a tripartite shell and only very incomplete equatorial lines and other wall structures instead of the girdle-furrow and normal plates of the typical dinoflagellates.

MICROFOSSILS INCERTAE SEDIS
HYSTRICHOSPHAERIDEA? OR DINOFLAGELLATA?
FAMILIAE INCERTAE

Genus **Triblastula** O. Wetzel, 1933

Description (based on the 1933 diagnosis): Shells tripartite in the axial direction. A spheroidal central body bears two hemispherical or cylindrical segments at each end of the equatorial surface. Usually the two "pole-caps" differ in the form and ornamentation of their ends (apical and antapical). The central portion may be covered with a more or less spiny surface, but the naked ones show the pylomes more clearly when they are present.

Type species: Triblastula utinensis O. Wetzel, 1933.

Triblastula utinensis O. Wetzel
Plate 2, figure 1

Triblastula utinensis O. WETZEL, 1932, Zeitschr. Geschiebef., vol. 8, no. 3, p. 136, pl. 2, fig. 11; 1933, Palaeontographica, vol. 78, pp. 54–55, pl. 6, figs. 5–6.

Neotype: Collection of O. Wetzel, Eutin; slide no. 2109b.

Age and occurrence: Sporadic in Baltic Cretaceous flintstones and chalk samples.

Description (based on the 1933 diagnosis): Central portion covered with bristles, which are sometimes furcate and extending over the other segments. One of the two "pole-caps" is especially strongly formed and may resemble a round box, having a large terminal point with circular rows of small protuberances. Pylome-like openings occur.

Dimensions: 130 × 50μ; 105 × 60μ.

Remark: Since the holotype has been lost, a neotype is substituted for it.

Triblastula nuda O. Wetzel, new species
Plate 2, figure 2

"Dreiteilige Hülle (stachellose *Triblastula?*)" O. WETZEL, 1932, Zeitschr. Geschiebef., vol. 8, no. 3, p. 136, pl. 2, fig. 14.
"Dreiteilige Hüllen (stachellose Triblastulae?)" O. WETZEL, 1933, Palaeontographica, vol. 78, p. 21, pl. 3, fig. 23.

Holotype: Collection of O. Wetzel, Eutin; slide no. A2360.

Age and occurrence: Common in Baltic Cretaceous flintstones.

Description (based on the 1933 diagnosis): Central portion spheroidal, smooth, without spines. Usually only one of the "pole-caps" has a terminal point (apex); the other is more cuboidal or cylindrical, narrowing somewhat at the end. The caps often have four longitudinal striations, which may indicate the corners of the broad areas or fields of the shell. The circular bases of the two caps together appear as a narrow pair of parallel lines, and may represent the equatorial "girdle" of a true dinoflagellate. "Pylomes" are apparently not rare.

Dimensions: 96 × 48μ; 100 × 45μ.

Comments: With regard to their *Scriniodinium galeatum*, Cookson and Eisenack (1960) stated that they were "aware that it differs in shape very considerably from that of the genotype, *Scriniodinium crystallinum* (Deflandre)," which the same authors in 1957 had called *Gymnodinium crystallinum* Deflandre. The type species of the genus *Scriniodinium* Klement, 1957, mentioned by Cookson and Eisenack (1960, p. 3) in discussing their new species, is otherwise unknown to me, but I assume that, at all events, my *Triblastula* forms do not belong to *Scriniodinium* and that *Scriniodinium galeatum* Cookson and Eisenack would be more suitably included in the genus *Triblastula* because of its resemblance to *Triblastula nuda.*

Remark: This fossil was previously described and illustrated in 1933. In that first discussion of the "Stacheleier-Problem," I had to content myself with including the spiny membranous microfossils in the new family "Hystrichosphaeridae," but I emphasized the close relationship of the "naked" tripartite forms to the typical species by using the designation "spineless Triblastulae(?)."

Triblastula tubulata O. Wetzel, new species
Plate 2, figure 4

Holotype: Collection of O. Wetzel, Eutin; slide no. A 2360.

Age and occurrence: Rare in Baltic Cretaceous flintstones.

Description: Overall appearance slender, the tripartition less abrupt than in *Triblastula nuda* O. Wetzel; like that form, it also lacks bristles. The two "pole-caps" narrowly embrace the equatorial circle of the central sphere and are drawn out with somewhat concave outlines in opposite directions; one (the "epitheca") ends in a short, humplike "apex," but the other remains cylindrical, like a truncated tube. A pylome appears to be present below the "apex"; in other respects the fossil is not sufficiently transparent to permit further observations.

Dimensions: 80 × 45μ.

Triblastula quasicribrata O. Wetzel, new species
Plate 2, figure 3

Holotype: Collection of O. Wetzel, Eutin; slide no. A 2375.

Age and occurrence: Rare in Baltic Cretaceous flintstones and chalk.

Description: Central body spheroidal and spineless. Both "caps" are cylindrical-cuboidal, narrower toward the ends, especially the one ("epitheca") having a more projecting field of pore-meshes with terminal edges protruding. "Pylomes" are common.

Dimensions: ca. 100 × 50μ.

Comment: Amphidiadema denticulata Cookson and Eisenack (1960) appears closely similar to this species of *Triblastula*, but it differs in the terminal portions, which are smaller and more open but not "quasicribrate" (i.e., perforated like a sieve). The authors themselves regarded their new species as closely related to another of their new forms, *Deflandrea tripartita* Cookson and Eisenack (1960) (see my remarks under *Bulbodinium* O. Wetzel, 1960, below).

Triblastula sp. indet.
Plate 2, figure 5

Figured specimen: Collection of O. Wetzel, Eutin; slide no. A 2421.

Age and occurrence: One specimen in a Baltic Cretaceous flintstone.

Description: Central body spheroidal, without spines but partly covered with a network of lines. The "pole-caps" have a flattened terminal region and differ somewhat in size and outline.

Remark: The figured specimen is a special case, as the "epitheca" has been shifted upward and lies obliquely; it prevents a dark disk from escaping, which is undoubtedly the round lid and has the appropriate form for the "pylomar" opening at the upper end of the central body.

DINOFLAGELLATA
INCERTAE FAMILIAE
(NON DEFLANDREIDAE?)

Genus **Bulbodinium** O. Wetzel, 1960

Type species: Bulbodinium seitzi O. Wetzel, 1960.

Remark: My German paper on these microfossils was in press and publication in 1960 was anticipated as the present paper was submitted for publication. Because of their resemblance to some microfossils from the Australian Cretaceous recently described by Cookson and Eisenack (1960), it appears desirable to describe them here in English as well.

Description (based on the 1960 German diagnosis): In contrast to all other fossil and extant microorganisms (so far as I am aware) that have been described to date (i.e., through 1959) and referred to the Dinoflagellata, this form has the body clearly divided into three rather than two segments. However, when some of my specimens were isolated chemically from the flintstone matrix, the very flat "girdle" of the equatorial region became distinct, or at least some parts of it. This structure seems to replace the transverse furrow characteristic of the typical dinoflagellates (peridinians), separating their epitheca and hypotheca from one another. Instead of a regular arrangement of plates, the wall of the typical *Bulbodinium* shell is more or less granular or areolar and has, at most, some wide fields with indistinct borders. The central portion of the body, which may be a highly inflated, block-shaped "capsule," extends outward, and the eiptheca may also extend outward, but less so, below the "apical" point, which is often blunted. The hypotheca has a square outline and may be prolonged into a "horn" at one of the terminal edges.

Comments: The type species of *Bulbodinium* appears to be closely similar to *Deflandrea tripartita* Cookson and Eisenack (1960), but it differs in the distinct transverse delimitation of the central portion from both external segments, which are longer than the corresponding ones in the new Australian form and all previously described species of *Deflandrea* that I have seen. In addition, there are other species of *Bulbodinium* with forms that are even more slender than the type species and do not resemble the true *Deflandrea* species.

Bulbodinium seitzi O. Wetzel
Plate 2, figures 6 (upper) and 7–8

Holotype: Collection of O. Wetzel, Eutin; slide no. A 1269.

Age and occurrence: Nearly 20 specimens in one Baltic Cretaceous flintstone; one, possibly identical, in an English Cretaceous flint.

Description: See that of the genus above and my German paper (1960).

Dimensions: $128 \times 65\mu$; $112 \times 64\mu$.

Bulbodinium altipetax O. Wetzel
Plate 2, figures 6 (lower) and 9

Holotype: Collection of O. Wetzel, Eutin; slide no. A 1266.

Age and occurrence: A few specimens in the same Baltic Cretaceous flintstone as above.

Description (based on the German diagnosis of 1960): Shell more slender, more concave in outline, and more pointed terminally than in *Bulbodinium seitzi*.

Dimensions: $135 \times 60\mu$.

Bulbodinium oistoides O. Wetzel
Plate 2, figure 10

Holotype: Collection of O. Wetzel, Eutin; slide no. A 1267.

Age and occurrence: Only two specimens, rather similar to each other, in the same Baltic Cretaceous flintstone as above.

Description (based on the German diagnosis of 1960): Overall appearance very slender. The equatorial region of the central body extends outward with two small protuberances situated obliquely opposite each other. One of the terminal segments has a more or less pointed "apex" resembling a beak. The other one ("hypotheca") is nearly tubiform and ends bluntly. Because of its opacity, the individual structures of the shell are almost imperceptible.

Dimensions: $120 \times 50\mu$.

TAXONOMY OF TRIBLASTULA AND BULBODINIUM

The species of *Triblastula* and *Bulbodinium* described above may all belong to the same family or superfamily and be united across the taxonomic boundary between the Hystrichosphaeridea and Dinoflagellata, but they can not be assigned to the family Deflandreidae Eisenack (1954, p. 52), which was intended to include more compact and less elongate forms than the present objects. As for the few points of similarity between my *Bulbodinium* species and the extant form *Heterodinium* Kofoid, 1906, mentioned in my German paper of 1960, it is likewise impossible to place my tripartite microfossils taxonomically in the vicinity of that genus. In any case, this is not the first time that some fluctuation has persisted in the taxonomic assignment of new microfossils of intermediate form. For example, even today I am not entirely certain that *Peridinium illustrans* O. Wetzel (1932–33), which was originally assigned to a separate division of fossil Peridiniidae, i.e., to the Dinoflagellata, was correctly classified. As its general appearance is like certain sparsely spined hystrichospherids, I chose the specific name to indicate that it illustrates the close relationship between such hystrichospherids and the dinoflagellates. Unfortunately, the type specimen, the only well-preserved representative of this form, has been lost, but figure 11 of plate 2 here shows the resemblances mentioned (total dimensions $34 \times 28\mu$).

RADIOLARIA AND HYSTRICHOSPHAERIDEA OF SIMILAR FORM

In general, the siliceous shells of diatoms, being very delicate, are easily dissolved, and they are totally lacking in the Baltic Cretaceous flintstones, except for the unusual case of "*Trinacria* sp.," a chain of "horned" diatom shells preserved in a non-siliceous substance in an erratic flintstone (slide no. A 1873, collection of O. Wetzel, Eutin). Radiolaria, however, have rarely been found in the flintstones, preserved only by pseudomorphic replacement of their skeletons, which are mainly in fragments. As a rule, specific identification of the specimens is impossible, and not all of the forms figured in earlier publications are true Radiolaria as understood today; some of them may preferably be assigned to the Hystrichosphaeridea (see below).

I recently found two delicate pyritized skeletons, the fragments of which lay almost on top of one another in the flint matrix. One of them, which is figured here in plate 3, figure 1, is 130 × 40μ in size, and may be another species of *Dictyomitra*, different from the one previously figured (O. Wetzel, 1932–33, pl. 3, fig. 1). The other specimen may be recorded here as follows:

Class Radiolaria
Order Spumellaria
Suborder Collodaria
Family Thalassothamnidae Haecker
Genus Cytocladus Schröder

Cytocladus tricladus Haecker
Plate 3, figure 2

Cf. *Cytocladus tricladus* Haecker. – Tregouboff, 1953, in Grassé, Traité de Zool., vol. 1 (Protozoaires), pt. 2, pp. 335-340, text-fig. 224.

Figured specimen (fragment): Collection of O. Wetzel, Eutin; slide no. A 2340.

Age and occurrence: The present fragment, found in a Baltic Cretaceous flintstone, is the first and only fossil specimen.

Description: A long thin shaft is based on a short trunk, then divides into two branches, each of which is trifurcated at the end. The surfaces of the terminal portions may have been somewhat rough (or this effect may merely be an irregularity due to preservation).

Dimensions: Fossil fragment (total) 180 × 130μ; trunk 30 × 20μ.

Comments: This microfossil closely resembles a single ray of the simple stellate skeleton of the extant radiolarian *Cytocladus tricladus* Haecker, which has a highly ramified central capsule. The discovery of this microfossil, which undoubtedly belongs to the family Thalassothamnidae, so far as I can judge, supports the classification of a form previously found in a flintstone (see pl. 3, fig. 3), the pyritized fragment described by O. Wetzel (1933, p. 5, pl. 3, fig. 8). I believed that it was not a bristle or spine of a plant but a fragment of the skeleton of a radiolarian related to *Oroscena regalis* Borgert or belonging to *Thalassothamnus;* the size of the former is 4–5 mm. and of the latter ca. 14 mm. for the diameter of the total living sphere.

RADIOLARIA OR HYSTRICHOSPHAERIDEA?

A new microfossil, hitherto published only as figure 19 on plate 1 in O. Wetzel (1957), is worthy of fuller notice here. In addition, I have recently become aware that another microfossil found in the Tertiary of South America, which is still problematical and may be a radiolarian, resembles my new fossil to some degree. The latter is therefore formally described as follows:

Uncertain Radiolarian
Order Nassellaria?
Suborder Plectoidea (Haeckel) Popovsky?
Familia Incerta

Genus **Rhizoplectopsis** O. Wetzel, **new genus**

Description: Skeleton rounded polygonal, with a radiolarian-like lattice structure. Meshes with thick borders and of different sizes. More or less elongate spines originate at some of the outer corners. The arrangement of the protuberances seems to be similar to that in typical species of the suborder Plectoidea.

Type species: Rhizoplectopsis baltica O. Wetzel, 1961.

Rhizoplectopsis baltica O. Wetzel, **new species**
Plate 3, figure 4

Holotype: Collection of O. Wetzel, Eutin; slide no. Jt. 105a.

Age and occurrence: One specimen in a Cretaceous flintstone from Moens Klint, Denmark.

Description: See that of the genus, above.

Dimensions: Diameter 140–180μ.

Remarks: The central portion of this fossil is dark due to pyritization, and it is impossible to observe the internal structure of the skeleton; in addition, the lattice seems to be partly broken away on the exterior and to have lost one or more spines (note the isolated one near the body).

Comments: The other microfossil mentioned above as comparable to the present form is *Rhizoplecta trithyris* Frenguelli (1940), which was cited by Deflandre (1953, p. 423, text-fig. 320 A); it appears to have a "spicule triaxone" in its juvenile condition (see Deflandre's text-fig. 320 B).

SYSTEMATIC POSITION OF CANNOSPHAEROPSIS

The Hystrichosphaeridea not only show relationship to the Dinoflagellata, but also frequently resemble typical Radiolaria to some extent. Indeed, at the start of his systematic studies of the hystrichospherids, the author of the genus *Cannosphaeropsis* O. Wetzel (1933) classified it in the taxonomic unit Tripylea R. Hertwig (= Phaeodaria Haeckel), specifically in the family

Cannosphaeridae Haeckel, because the species *C. utinensis* O. Wetzel (see pl. 2, fig. 12) very closely resembles *Cannosphaera geometrica* Borgert, of the extant marine plankton. But even then some limitations were apparent in this classification (see O. Wetzel, 1933, p. 9), among other things, with respect to its organic substance, as I then pointed out. Later, Deflandre stated that my microfossil should be united with his genus *Hystrichosphaeridium* Deflandre, 1937. Other species showing transitional forms between *Cannosphaeropsis* and *Hystrichosphaeridium* were recorded by Deflandre (1947*a*)as new species of *Cannosphaeropsis* O. Wetzel, 1933, the latter being included in the Hystrichosphaeridea.

In spite of the changed opinions of Deflandre and the present author, a few modern textbooks still report that *Cannosphaeropsis* indicates the geologic longevity of the radiolarian order Phaeodaria (= Tripylea), as its only fossil representative. Aside from this failure to correct an early provisional opinion, it is still possible, nevertheless, that some Hystrichosphaeridea were in a general manner connected with the Radiolaria as well as with the Dinoflagellata. In this regard, *Hystrichosphaera furcata* (Ehrenberg) of O. Wetzel (1932–33) (figured here in pl. 2, fig. 15) may be a conspicuous example, with its one additionally prolonged "apical" protuberance. Such an abnormal structural development was first described by O. Wetzel (1932–33, pl. 5, fig. 4), and similar "aberrations" occur rather frequently in the skeletons of radiolarians. In addition, there are modern optical and chemical methods which permit views of the animal's molecular structure as well as some probable primary siliceous substance in the fossil skeletons of *Cannosphaeropsis* species and other radiolaria-like Hystrichosphaeridea.

OCCURRENCE OF OTHER SPECIES OF CANNOSPHAEROPSIS

Cannosphaeropsis is apparently represented in the Baltic Cretaceous first by the rather common species *C. utinensis* O. Wetzel, which has been isolated not only from the flintstone but also from the Senonian chalk (see pl. 2, fig. 12). Two other specimens found later in flintstones do not belong to the type species. The first one is *Cannosphaeropsis* (*Hystrichosphaeridium*) *aemula* Deflandre, 1938 (1947) (see pl. 2, fig. 13); the flintstone enclosing it was collected near the southern limit of the Baltic glacial area and may possibly have come from pre-Senonian or pre-Cretaceous sediments. The other specimen has a strange appearance due to the protuberances (8–12?), terminally bearing an indistinct group of round meshes or irregular points (see pl. 2, fig. 14). It may be additionally deformed or merely a variety of a previously described species, e.g., *Cannosphaeropsis reticulensis* A. Pastiels, 1948, or *Cannosphaeropsis aemula* (see O. Wetzel, 1953*b*, pl. 83, fig. 20).

A NEW INDETERMINATE MICROFOSSIL

The present form does not appear to be related to any other known species, but is best included provisionally in the morphologic group Hystrichosphaeridea.

Microfossil Incertae Sedis (Hystrichosphaeridea?)

Genus **Coronopsis** O. Wetzel, new genus

Description: The main portion of the microfossil is a thick "wreath" (see remarks below). Upon it, several (about six) long, spoon- or finger-shaped prominences are set in a somewhat irregular arrangement; they seem to be attached by some very small rootlike ramifications. Terminally, the thin "handle" becomes broader and flatter and forms a bifurcated oval top with a few round openings in the "bowl."

Type species: Coronopsis digitata O. Wetzel, 1961.

Coronopsis digitata O. Wetzel, new species
Plate 3, figure 11

Holotype: Collection of O. Wetzel, Eutin; slide no. A2350 (pl. 3, fig. 11).

Age and occurrence: One specimen, from a Baltic Cretaceous flintstone.

Description: See that of the genus, above.

Dimensions: Diameter (total) 50μ; corner of the "wreath" 15μ thick; top of the "finger" 5μ broad.

Remarks: The fossil may be somewhat compressed and cracked; as its position within the flint chip shows only the corner of the "wreath," it is possible that there is a membrane connecting the corner with the center of the circular portion, to form a disc.

Comments: The overall appearance of this microfossil somewhat resembles (although only superficially) the shape of some Suctoria, i.e., Ciliata, such as *Dendrocometes paradoxus* Stein, which have lost their cilia and live as parasites. However, it is possible that some sort of parasite is actually present here.

REMAINS OF ECHINODERMS AND SIMILAR MICROFOSSILS

In the course of my studies of flintstone chips, the number of observed sclerites of Holothuroidea has gradually increased. I recently found a large wheel-shaped specimen (see pl. 3, fig. 5), 240μ in diameter. It probably belongs to the form-genus ("manipulus") *Myriotrochites* Deflandre-Rigaud, 1948, being similar to *Myriotrochites elegans* (Schlumberger) Deflandre-Rigaud, which was first taken for a disciform diatom by F. Hustedt (see pl. 3, fig. 6, and O. Wetzel, 1950, pp. 174–176, 190; 1951, pp. 102–103). In 1953 (1953*a*, p. 42, pl. 2, figs. 20–21), I published descriptions to two other radiolarian-like specimens from the flintstone, which were identified as *Chiridotites* cf. *ingens* and *Chiridotites atavus* by Deflandre-Rigaud. In addition, it is barely possible that another of my problematic microfossils of 1953 (1953*a*, pp. 39–40, pl. 1, fig. 14), reported there as "*Gymnodinium* cf. *Actiniscus elegans* Ehrenberg" (pl. 3, fig. 7), is also a sclerite, similar to *Mortensenites sievertsi* Deflandre-Rigaud (1953, p. 954, text-fig. 17).

With regard to pedicellariae (peculiar organs from the surface of fossil echinoids), M. F. Glaessner cited some publications by Geis and Mortensen and figured one set of a type which was called "ophiocephalous" (Glaessner, 1947, p. 24, pl. 4, fig. a–d). Still other forms were described by W. Wetzel (1953, p. 175, text-figs. 4–6), who disintegrated flintstone chips (mostly from the Danian) in dilute hydrofluoric acid and observed a few very small arrow-shaped specimens in a pseudomorphous condition among the residues. I too have recently found occasional pedicellariae of almost the same form and size, which may have belonged to an echinoid related to the extant genus *Saleniocidaris*, possibly to a dwarf form of it (see pl. 3, figs. 8–9).

SCOLECODONT ASSEMBLAGES

Since the publication of my paper of 1932–33, showing the variations in the forms of scolecodonts, I have consistently found single specimens or pairs in the Baltic Cretaceous flintstones. In two cases, however, I have observed an assemblage (more than two) of specimens very similar to each other (see pl. 3, fig. 10). These forms may represent a variety of "Kammzahn a" or of a form such as that figured in 1932–33 (pl. 6, fig. 23). The dimensions of the total assemblage are about 270 × 65μ; one is 110 × 70μ (slide no. A 2165). In purely morphological respects, they resemble an assemblage of conodonts figured in Pokorny's recent textbook of micropaleontology (1958, vol. 2, p. 62, text-fig. 610). The other assemblage found in the flintstones contains some (four?) handlike "mandibles," which are brown and partly marked with small spots. The dimensions of a long specimen are 175 × 65μ (slide no. A 2141).

WORMLIKE AND TUBIFORM FRAGMENTS

A few microfossils may be united under this heading which at first appeared to be insignificant and of very uncertain origin. However, in my opinion they may be worthy of some notice in connection with later observations of additional, more complete specimens. One of the present fragments can be recorded at the present time and classified with some assurance in a taxonomic division that is of particular biological interest:

Division Stomochorda Davydoff, 1948?
Class Pterobranchia Ray Lankester, 1878?
Order Rhabdopleurida?
Genus Rhabdopleura Allmann?

Rhabdopleura? sp. cf. **R. normanni** Allmann
Plate 3, figure 12

Figured specimen: Collection of O. Wetzel, Eutin; slide no. A 2463.

Age and occurrence: One specimen, from a Baltic Cretaceous flintstone.

Description: Body long, cylindrical, and coiled in a wormlike manner. At one end it tapers to a somewhat conical form; at the other end it is broken away. In the central region it is broken nearly into two pieces, and there is a smaller cleft near the conical end. In these places, an axial cord ("stolon"?) is still preserved and clearly visible, which evidently runs longitudinally, but perhaps not quite centrally, through the entire fragment. The body wall is divided into numerous small transverse segments, apparently covered with scaly plates or meshes. Color brownish. Substance probably chitinous.

PLATE 1

1–2 Two different spp. indet. ex aff. Reophacidae?
Erratic flints; slide nos. A 2178, A 2454; × ca. 250 and ca. 100.

3–4 Two different spp. indet. ex aff. *Chitinodendron* Eisenack, 1937
Senonian flint from Stevns Klint, Denmark, or erratic flint; slide nos. A 350, A 124; × ca. 50 and ca. 100.

5 Foraminifera gen. et sp. indet. ex aff. Rhizamminínae?
Erratic flint; slide no. A 2327; × ca. 175.

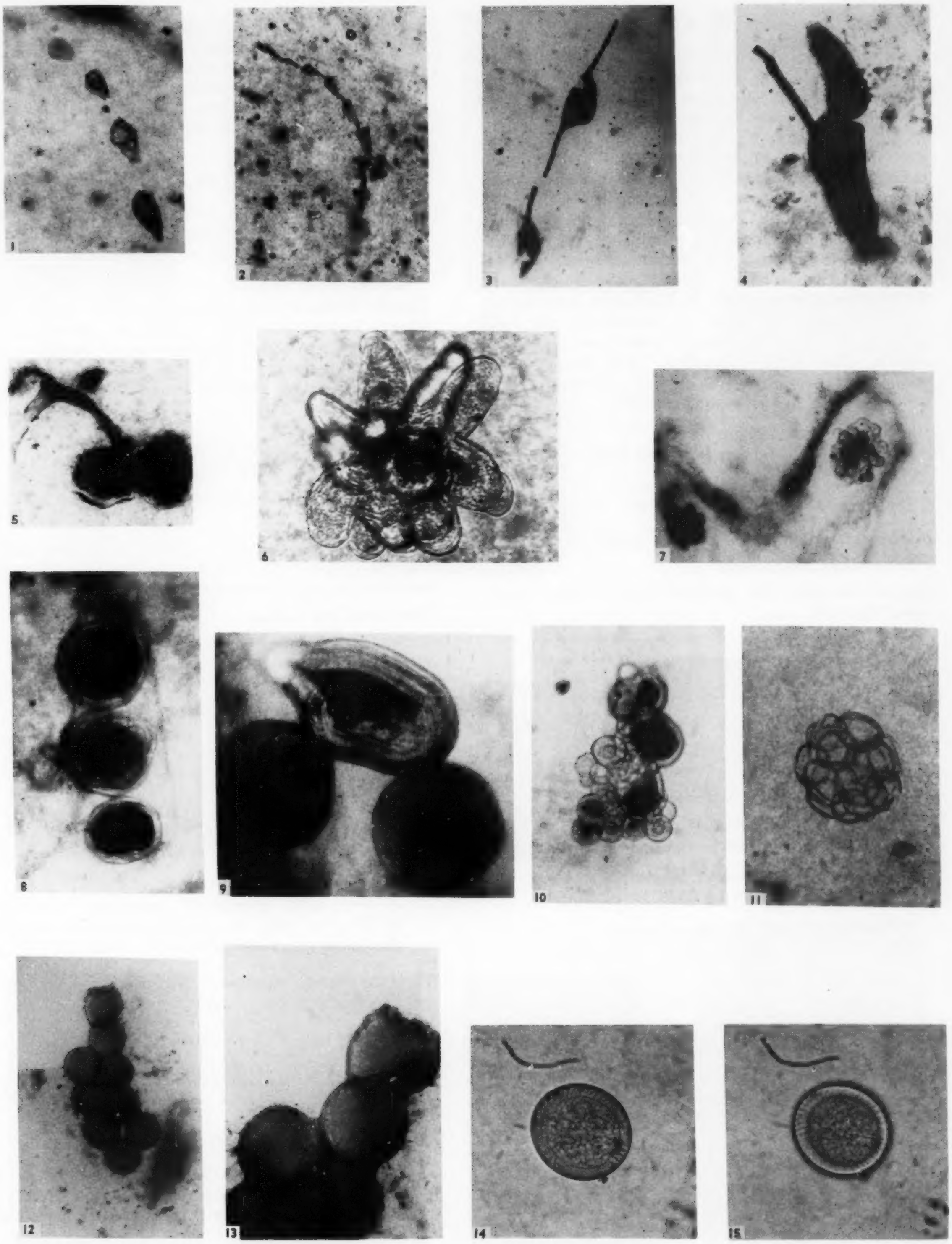
6–7 *Pseudastrorhizula eisenacki* O. Wetzel
Erratic flints; slide nos. A 1022, A 2160. 6, free in flintstone, × ca. 300; 7, within the chambers of a bryozoan colony, × ca. 15.

8–10 "Brown bodies" of fossil Bryozoa ("ovoids" of O. Wetzel, 1950)
Erratic flints; slide nos. A 1583, A 1580, A 2159. 8, a set of three bodies, with a radial "blastula"-like structure in the middle one, × ca. 110; 9, another set, with concentric layers and excrescences in the largest one, × ca. 175; 10, probably a close association of egglike "brown bodies," free in the flint chip, × ca. 125.

11 *Palambages morulosa* O. Wetzel, n. sp. (= "Morulosae" of O. Wetzel, 1933)
Cretaceous flintstone from Stevns Klint, Denmark; slide no. A 350; × ca. 250.

12–13 *Palaeobion catenatum* O. Wetzel, n. sp.
Erratic flint; slide no. Jt. 75a. Two different views, × ca. 10 and ca. 170.

14–15 *Pleurozonaria globulus* O. Wetzel
Erratic flintstone (Cretaceous or Jurassic?) from Krywonogi, Poland; slide no. A 405. Two different views, both × ca. 400.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Dimensions (fragment): 180 × 15μ.

Comments: Although this microfossil has the general form of an annelid worm, it also resembles the structure of other organisms in fragments to some extent. Having attempted to exhaust the possibilities for satisfactorily identifying my "problematicum" by comparison with the forms most recently described in the literature, I came to the conclusion that the classification given above is the best provisional one (see Waterlot, 1953, "Pterobranches," in Piveteau, pp. 963–966, text-figs. 1–6). In the latter publication there are descriptions not only of the external and internal organization of the living organism (colonies), but also of some rare fossil fragments recently found by R. Kozlowsky in the Upper Cretaceous (Maestrichtian) of Poland. In my fossil specimen the buds for additional growth are lacking, as well as the "blastoïde inachevé," but the fragment, with its conical termination, may have been a young portion belonging to a minute species.

Microfossils Incertae Sedis

"Form B" (fragment)
Plate 3, figure 13

Figured specimen: Collection of O. Wetzel, Eutin; slide no. A 2416.

Age and occurrence: One specimen, from a Baltic Cretaceous flintstone.

Description: Body elongate-cylindrical, coiled in a wormlike manner; ends indistinct (broken away?). At least part of the specimen seems to be divided more or less regularly into segments, which differ in size and transparency. On the whole, the fragment has a granular structure and vague color, but it is probably of organic origin.

Dimensions: About 400 × 40μ.

Comments: The structure (or the preservation) is different from that of the preceding form, and it is difficult to decide whether or not the object was produced by a true worm (annelid?).

Remark: Under the central portion of the elongate fossil there is another microfossil, which is probably a hystrichospherid in a delicate, transparent condition. Its radial protuberances are curved and end in furcate tops; a round dark plate lies in the interior (the lid of a "pylome"?).

"Form C" (fragment)
Plate 3, figure 14

Figured specimen: Collection of O. Wetzel, Eutin; slide no. A 2406.

Description: Fragment tubular, enlarged at intervals and truncated at the ends. Wall finely granular and bearing numerous annular transverse lines. Color brownish.

Dimensions: 240 × 65μ.

PLATE 2

1 *Triblastula utinensis* O. Wetzel
Erratic flint; slide no. 2109b; × ca. 220.

2 *Triblastula nuda* O. Wetzel, n. sp.
Erratic flint; slide no. A 2360; × ca. 325.

3 *Triblastula quasicribrata* O. Wetzel, n. sp.
Erratic flint; slide no. A 2375; × ca. 200.

4 *Triblastula tubulata* O. Wetzel, n. sp.
Erratic flint; slide no. A 2360; × ca. 250.

5 *Triblastula* sp. indet.
Erratic flint; slide no. A 2421; × ca. 205.

6 Upper: *Bulbodinium* cf. *seitzi* O. Wetzel; lower: *Bulbodinium* cf. *altipetax* O. Wetzel
Residues from chips of an erratic flint disintegrated with hydrofluoric acid; specimens figured together but lost in further preparation. × ca. 175.

7–8 *Bulbodinium seitzi* O. Wetzel
Two typical specimens, tripartite with an inflated central portion; form seen as enclosed in an erratic flintstone (compare fig. 6). Slide nos. A 1269, A 1264; × ca. 185 and ca. 205.

9 *Bulbodinium altipetax* O. Wetzel
Erratic flint; slide no. A 1266; × ca. 155.

10 *Bulbodinium oistoides* O. Wetzel
Erratic flint; slide no. A 1267; × ca. 170.

11 *Peridinium illustrans* O. Wetzel
A very small microfossil resembling both the peridinians and the hystrichospheres. Erratic flint; slide no. A 700 (slide lost); × ca. 150.

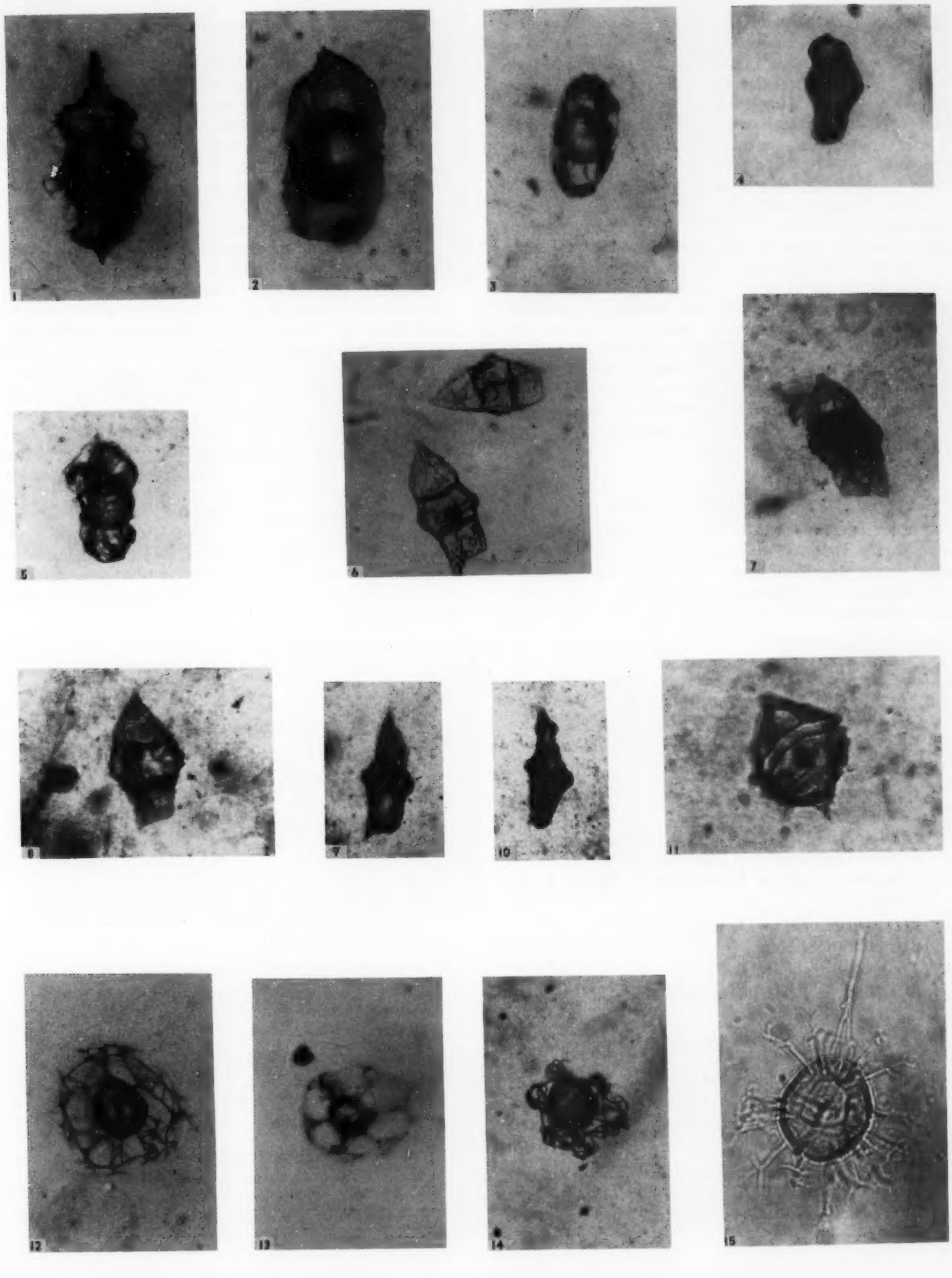
12 *Cannosphaeropsis utinensis* O. Wetzel
Erratic flint; slide no. A 612; × ca. 195.

13 *Cannosphaeropsis (Hystrichosphaeridium) aemula* Deflandre
Erratic flint; slide no. Mü. 8; × ca. 160.

14 *Cannosphaeropsis* sp.
Erratic flint; slide no. A 1738; × ca. 175.

15 *Hystrichosphaera furcata* (Ehrenberg) of O. Wetzel
Aberrant, with one additional prolonged "apical" protuberance. Senonian chalk residue from Stevns Klint, Denmark; slide no. A 1104; × ca. 440.

PLATE 2



Comments: The present fragment is very similar to the tubiform portions of problematica that I isolated at an earlier date from some Liassic samples. At the 1957 annual meeting of the German Paleontological Society in Freiburg i. Br., I reported my observations of these Liassic residues, which were assumed to be fossil remains. I proposed to establish provisionally an independent morphologic group of organisms to include these problematic microfossils, to be called Anellotubulata ("ring-tubers"). For, in spite of having some resemblance in shape and size to certain extant organisms, especially coelenterates (the tubes of polyps), they are nevertheless different and cannot be included in any systematic unit known to date. If further specimens are found, exact identification will, perhaps, be possible, and the nature of my present fragment may become determinable. In any case, I have appended here (pl. 3, fig. 15) an illustration of one of these Liassic supposed anellotubulates. I have not previously published any illustrations or detailed descriptions of these "ring-tubers," merely some notes in a paper read by title (O. Wetzel, 1959).

REMARKS ON THE "FLAGELLA" OF FOSSIL OPHIOBOLUS

The occurrence of "flagella" on fossil *Ophiobolus* specimens in the Baltic Cretaceous flintstones is most unusual, as the flagella of extant organisms are ordinarily very transitory in preparations made from living specimens. Perhaps it can be assumed that these so-called "flagella" actually had some special function as cellular organelles on the body of the *Ophiobolus* during its life in the Cretaceous ocean. The same is true of species of *Dimastigobolus* Deflandre, another genus of the Ophiobolidae. The "flagellum" could have been a kind of thread which served to attach the living organism to some other object, e.g., another organism to be eaten. There are many extant flagellates of the genus *Chrysochromulina* which, in addition to their true flagellum, also have a so-called "haptonema," which is often attached to some support during a brief resting period (see the extensive studies on such marine flagellates by Mary Parke at the Plymouth Laboratory, 1956–1958). Miss Parke has had the kindness to grow some samples for me from cultures of individual species of algae. As for the microfossils in the flintstones, I am aware that the special mechanisms at the terminal end of the "haptonema" of living flagellates is apparently lacking in the Ophiobolidae and that it would be too difficult to study the microscopic structure in transverse thin sections of a fossil thread in a flintstone chip, which is very hard and brittle. Nevertheless, the "flagella" or cellular organs of the Ophiobolidae may have been composed of a special substance, appropriate to its function and differing from what is usual in most flagellates. Thus, the unusual composition of that organic material may have been more resistant to chemical destruction in the course of long geologic time, especially if the body was rapidly buried in the siliceous material that was to become the flintstone matrix.

PLATE 3

1 *Dictyomitra* sp. indet.
Erratic flint; slide no. A 2340; × ca. 175.

2 *Cytocladus tricladus* Haecker
A single radial spicule. Erratic flint; slide no. A 2340; × ca. 175.

3 *Oroscena* cf. *regalis* Borgert var. *oroplegmoides* Haecker or *Thalassothamnus* cf. *pinetum* Popofsky
A branched spicule. Erratic flint; slide no. A 33; × ca. 12/5.

4 *Rhizoplectopsis baltica* O. Wetzel, n. sp.
Erratic flint; slide no. Jt. 105a; × ca. 105.

5 *Myriotrochites* sp. indet.
A holothurian sclerite. Erratic flint; slide no. A 2450; × ca. 90.

6 *Myriotrochites elegans* (Schlumberger) Deflandre-Rigaud
A sclerite. Erratic flint; slide no. Ds. 2; × ca. 120.

7 *Gymnodinium* cf. *Actiniscus elegans* Ehrenberg or the sclerite *Mortensenites sievertsi* Deflandre-Rigaud
Erratic flint; slide no. A 1922; × ca. 155.

8–9 Pedicellariae (pseudomorphs) of an echinoid (dwarf form?) ex aff. *Saleniocidaris*
Erratic flint; slide nos. Mü. 3 and Mü. 5; both × ca. 120.

10 Assemblage of scolecodonts, perhaps of the same species
Erratic flint; slide no. A 2165; × ca. 155.

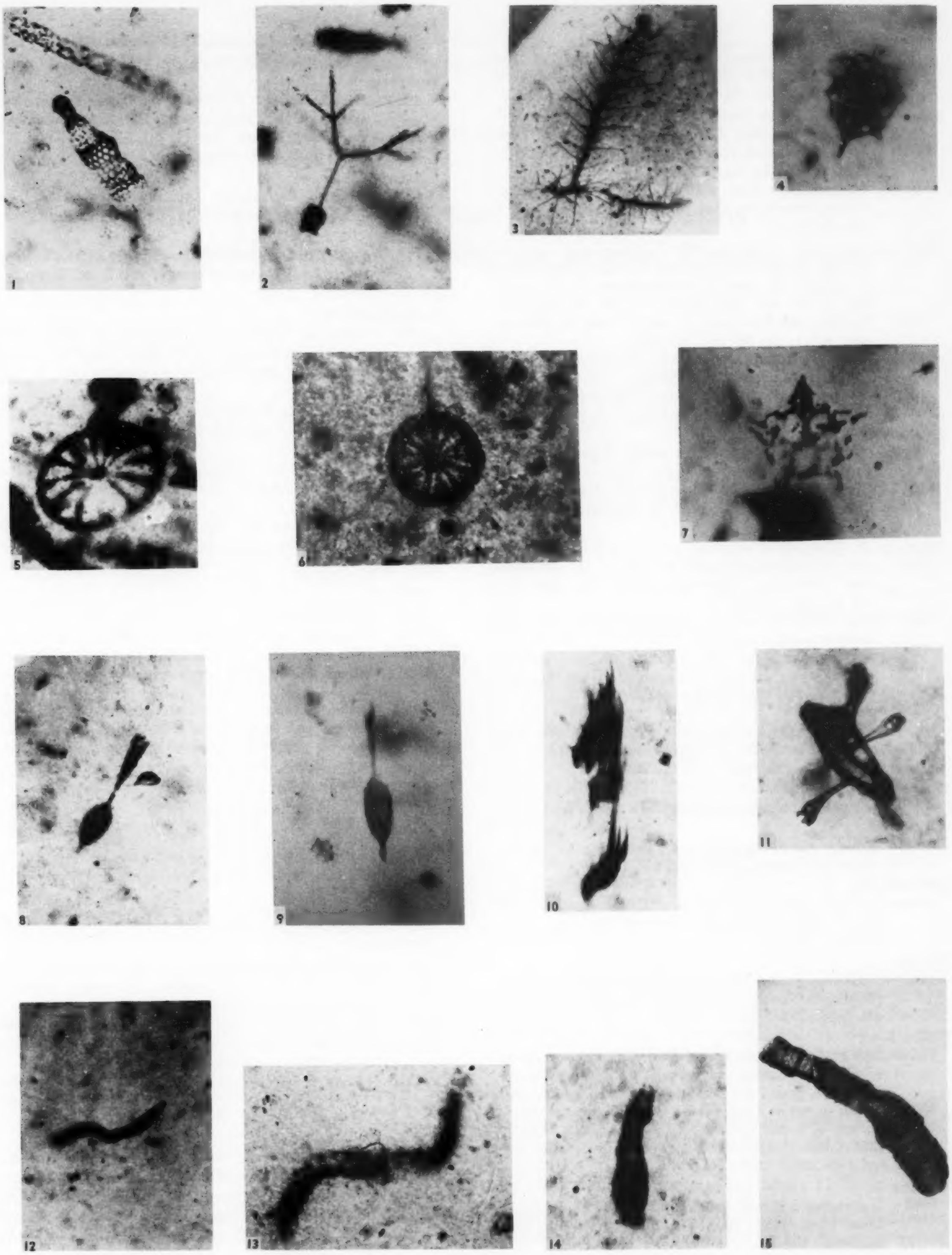
11 *Coronopsis digitata* O. Wetzel, n. sp.
A problematic microfossil. Erratic flint; slide no. A 2350; × ca. 375.

12 *Rhabdopleura?* cf. *normanni* Allmann
A wormlike tubiform fragment, probably from a colony of this pterobranch. Erratic flint; slide no. A 2463; × ca. 120.

13 Wormlike tubiform fragment "Form B," incertae sedis
Another microfossil (hystrichospherid?) lies near it. Erratic flint; slide no. A 2416; × ca. 120.

14 Wormlike tubiform fragment "Form C," incertae sedis
Erratic flint; slide no. A 2406; × ca. 100. Compare with fig. 15.

15 A simple tubiform representative of the problematic forms designated "Annelotubulata" ("ring-tubers") by O. Wetzel (1959)
Residue from a Liassic sample; slide no. Dea 10; × ca. 90.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ABSTRACT

A survey is presented of the micropaleontology and biostratigraphy of the middle Eocene Jacaguas group. The Jacaguas group contains an early middle Eocene planktonic assemblage correlating with Bolli's Hantkenina aragonensis *and* Globigerapsis kugleri *assemblage zones of Trinidad.*

The micropaleontology and biostratigraphy of the middle Eocene Jacaguas group, Puerto Rico

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INTRODUCTION

The Ponce–Coamo area includes about 400 square miles in south-central Puerto Rico. The geology of this area has been studied by Pessagno (MS.), by members of the U.S. Geological Survey (Mattson, Glover, et al., in progress), by Hodge (1920), and by Mitchell (1922). Microfossils were collected by the writer in conjunction with his study of the geology during the summers of 1956 and 1957, and from June, 1958, to January, 1959.

The rocks of the Ponce–Coamo area are divided into a deformed sequence of folded, faulted, intruded, but unmetamorphosed rocks, and an undeformed sequence of relatively flat-lying rocks. The deformed sequence in this area includes rocks of Cenomanian (Albian?) to early middle Eocene age. The undeformed sequence, which rests with angular unconformity on the deformed sequence, includes rocks of middle Oligocene to Recent age.

It was formerly believed that the rocks of the deformed sequence were entirely late Cretaceous in age (Meyerhoff, 1931). Recent work, however, has definitely confirmed the presence of early Tertiary strata within the deformed sequence (Kaye, 1956; Pessagno, 1960, MS.; Mattson, 1960; Slodowski, MS.). The present study shows extensive development of strata of early middle Eocene age in south-central Puerto Rico and has thereby yielded the youngest age for the rocks of the deformed sequence.

ACKNOWLEDGMENTS

The writer is particularly indebted to Dr. H. H. Hess of Princeton University for encouragement, advice, and weeks of supervision in the field. Dr. Hess also procured funds to pay for the scientific illustrations.

The aid of the following persons is gratefully acknowledged: Dr. A. G. Fischer, Princeton University; Dr. F. B. Van Houten, Princeton University; Dr. J. Harlan Johnson, Colorado School of Mines; and Mr. Guillermo Otálora, Princeton University.

Field expenses were financed by a contract with the Economic Development Administration of Puerto Rico. Dr. C. Vincenty, Director of the Industrial Research Department, and M. D. Turner, Chief Geologist of the same department, are thanked for their cooperation and interest. A jeep was furnished by the U.S. Navy under a contract (N6ONR-27008) between Princeton University and the Office of Naval Research. This vehicle greatly facilitated field work.

The drawings were made by Mrs. Joan Scott, Micropaleontology Laboratory, University of California, Berkeley.

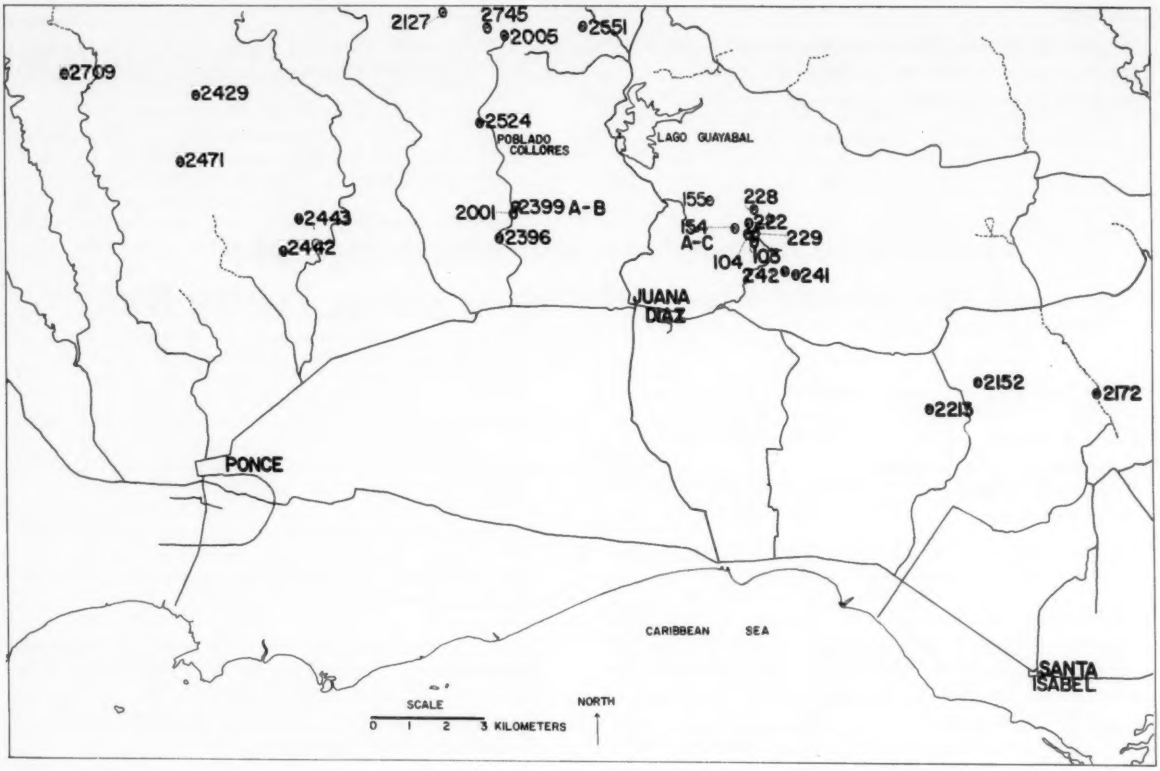
BIOSTRATIGRAPHY

Planktonic foraminifera were used in the zonation of the middle Eocene Jacaguas group. Eocene zonation follows that of Bolli (1957). The relationship of Puerto Rican strata to the zones established by Bolli in the Eocene deposits of Trinidad is shown in text-figure 3.

Hantkenina aragonensis assemblage zone

A microfaunal assemblage correlative with this zone was recovered from numerous localities in the lower part of the Jacaguas group. These localities are shown in Chart 1 and also on the index map (text-figure 1).

According to Bolli (1957, p. 158), "The *Hantkenina aragonensis* zone is characterized by the first occurrence



TEXT-FIGURE 1

of species of the genera *Hantkenina* and *Clavigerinella* together with a number of other planktonic species such as *Globigerina boweri* Bolli, new species, *Globorotalia bullbrooki* Bolli, new species, *G. spinulosa* Cushman, *G. pseudomayeri* Bolli, new species, and *G. spinuloinflata* (Bandy). *G. palmerae* Cushman and Bermudez, which is typical for the underlying *Globorotalia palmerae* zone, has disappeared together with a number of other species which persisted from the Lizard Springs formation."

The Puerto Rican assemblage differs somewhat from that of Trinidad by lacking *Hantkenina aragonensis* and species of *Clavigerinella* and by containing *Globigerapsis index* at several localities. *Globorotalia densa* Cushman (= *G. bullbrooki* Bolli) is the most abundant species at all localities.

Globigerapsis kugleri assemblage zone

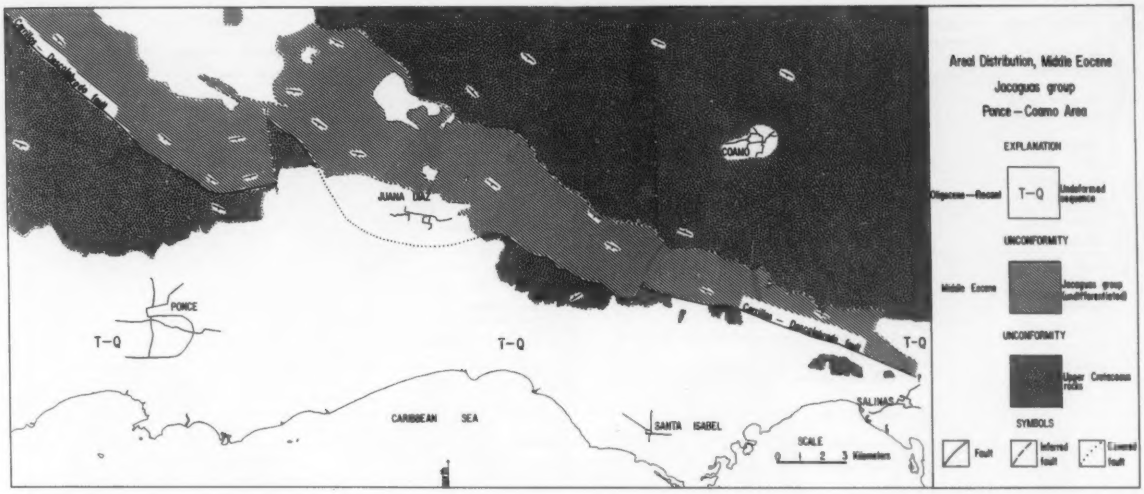
The upper portion of the Jacaguas group contains a planktonic assemblage correlative with this zone (Chart 1 and text-fig. 2).

According to Bolli (1957, p. 158), "*Globigerapsis index* (Finlay), *Globigerapsis kugleri* Bolli, Loeblich, and Tappan, *Globorotalia lehneri* Cushman and Jarvis, and *Globorotalia centralis* Cushman and Bermudez make their first appearance in the *Globigerapsis kugleri* zone, while several species, e.g., *Globorotalia aragonensis* Nuttall, *Globorotalia broedermanni* Cushman and Bermudez, *Globigerina boweri* Bolli, new species, and '*Globigerinoides*' *higginsi* Bolli, new species, become extinct at the top of this zone." The Puerto Rican assemblage correlates with the lower part of the *Globigerapsis kugleri* assemblage zone. *Globigerapsis kugleri* and *Globorotalia lehneri* which occur in the upper part of this zone in Trinidad are missing and rare, respectively.

LITHOSTRATIGRAPHY

Jacaguas group

The areal distribution of the middle Eocene Jacaguas group is indicated in text-figure 2. To the west of Poblado Collores (text-figure 1), the Jacaguas group consists largely of thin-bedded calcilutites and calcareous mudstones. To the east of Poblado Collores, it consists largely of volcanic conglomerates, calcareous siltstones, calcarenites, and distinctive calcirudites containing fragments of coralline algae such as *Archaeolithothamnion.* The exact thickness of the Jacaguas group is unknown at present because a large reverse fault, the Cerrillos-Descalabrado fault (text-fig. 2), abruptly cuts off its outcrop area to the south and because the se-



TEXT-FIGURE 2

quence has been repeated by a number of smaller faults (Mattson and Glover, personal communication). The Eocene rocks of the Jacaguas group occur on the southern flank of the large anticlinorium that forms the backbone of the island of Puerto Rico. They rest with angular unconformity on rocks of late Cretaceous (late Santonian to early Campanian) age and are overlain with marked angular unconformity by the basal unit of the undeformed sequence in southern Puerto Rico, the Juana Díaz formation of late middle Oligocene age, (Pessagno, MS., p. 70). The Jacaguas group is named after the Río Jacaguas situated near the town of Juana Díaz. The rocks are typically exposed in the area southeast of Lago Guayabal in the Juana Díaz Quadrangle.

SYSTEMATIC PALEONTOLOGY

Order Foraminifera
Family Lagenidae
Genus Lagena Walker and Jacob, 1798

Lagena nuttalli Galloway and Heminway

Lagena nuttalli Galloway and Heminway, 1941, New York Acad. Sci., Sci. Survey of Puerto Rico and the Virgin Islands, vol. 3, pt. 4, p. 346, pl. 10, fig. 8.

Occurrence: Lower part of Jacaguas group.

Family Ellipsoidinidae
Genus Ellipsoidina Seguenza, 1859

Ellipsoidina abbreviata Seguenza

Ellipsoidina abbreviata Seguenza, 1859, Eco Peleoritano, Giornale di Sco., Anno 5, fasc. 9, p. 14, pl., fig. 5a–b; Miocene, Italy.

Occurrence: Lower part of Jacaguas group.

Family Camerinidae
Genus Operculinoides Hanzawa, 1935

Operculinoides sp. aff. **O. willcoxi** (Heilprin)

Nummulites willcoxi Heilprin, 1882, Acad. Nat. Sci. Phila., Proc., pt. 2, p. 191, figs. 1–2.
Operculinoides willcoxi (Heilprin) – Barker, 1939, U. S. Nat. Mus., Proc., vol. 86, no. 3052, p. 309. – Cole, 1958, Bull. Amer. Pal., vol. 38, no. 173, pp. 273–276, pl. 33, figs. 1, 3–12.

Occurrence: Lower part of Jacaguas group.

Family Rotaliidae
Genus Gyroidina d'Orbigny, 1826

Gyroidina sp. cf. **G. jarvisi** Cushman and Stainforth

Gyroidina jarvisi Cushman and Stainforth, 1945, Cushman Lab. Foram. Res., Spec. Paper 14, p. 62, pl. 11, fig. 3.

Occurrence: Lower part of Jacaguas group.

Genus Globorotalites Brotzen, 1942

Globorotalites kochi (Pijpers)

Globorotalia kochi Pijpers, 1933, Geog. Geol. Med., Physiogr.-Geol. Reek, Utrecht, no. 8, p. 71.

Occurrence: Lower part of Jacaguas group. Upper Eocene of Bonaire (Dutch West Indies).

Family Hantkeninidae
Subfamily Hastigerininae
Genus Hastigerina Thomson, 1876

Hastigerina micra (Cole)
Plate 2, figures 1–2

Nonion micrus Cole, 1927, Bull. Amer. Pal., vol. 14, no. 51, p. 22, pl. 5, fig. 12.

AGE		ZONES (Bolli)	PUERTO RICAN FORMATIONS	TRINIDAD FORMATIONS
EOCENE	UPPER	Globorotalia cocoaensis	HIATUS	San Fernando
		Globigerapsis seminvoluta	HIATUS	
	MIDDLE	Truncorotaloides rohri	HIATUS	Navet
		Porticulasphaera mexicana	HIATUS	
		Globorotalia lehneri	HIATUS	
		Globigerapsis kugleri	Jacaguas group	Navet
		Hantkenina aragonensis		
	LOW.	Globorotalia palmerae	HIATUS	

TEXT-FIGURE 3

EOCENE CORRELATION CHART

(zones and stratigraphy after Bolli, 1957)

CHART I

MICROFAUNAL LIST. Jacaguas group

KEY: A = abundant; C = common; R = rare; ts = thin section; * = massive limestone

early middle Eocene

Hantkenina aragonensis assemblage zone = Ha

Globigerapsis kugleri assemblage zone = Gk

	103-B Ha	104 Ha	54-A Ha	54-C Ha	54-D Ha	55 Ha	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Textularia sp.				R																										
Clavulinoides sp.																		R												
Textulariella sp.									R																					
Coskinolina sp.										C																				
Robulus sp.	R		R	R																										
Dentalina sp.				C																										
Lagena sp. cf. L. nuttalli				R																										
sp.						R					R							R												
Operculinoides sp. aff. O. willcoxi																														A
sp.							C			C		R	A	C					C	R							C	C		
Pleurostomella sp.																					R									
Siphogerinoides sp.																								R						
Bulimina sp.				R																										
Ellipsoidina abbreviata											R																			
Ellipsoglandulina sp.																		R												
Eponides sp.		R	R	R	R				C																					
Gyroidina sp. aff. G. jarvisi					R																									
sp.			R	C					C																					
Globorotalites kochi	R										R																			
Amphistegina sp.							C			C				C																
Globigerina boweri			C	C	C				C		C					C					A		C	R						
turgida	A		C	A		C		C	A		R																			
sp. cf. G. turgida		R									R					C				R										
sp. aff. G. boweri	R	R	C		C			R																						
sp.	C		C		C	C		C							C		A	C												
Globigerapsis index			?		?				C									C												
sp.				?																										
"Globigerinoides" higginsi																		C					A							
Globorotalia densa	A	C	A	A	A				A		A							A			R		C	R						
broedermanni	A			R	C				C		R							C												
spinulosa	R																						A							
aragonensis																		R			C									
pseudomayeri																A														
sp. aff. G. densa																							C							
spinuloinflata																							R	R						
spinulosa transitional to lehneri																							C							
lehneri																					R		R							
sp. cf. G. pseudomenardii																					C									
sp.															C	A		C						C		A				
Anomalina sp.	R		R	R														R												
Cibicides micrus									R																					
Discocyclina sp.							C			C			C	C					C	R							C	A		
Miliolids							R											C												
Ostracods				R																										
Phacodiscus (?) sp.																		C												

CHART 1

Globigerinella micra (Cole) – GLAESSNER, 1937, Moscow Univ., Publ. Lab. Pal., vol. 1, fasc. 1, p. 30, pl. 1, figs. 4a–b.
Hastigerina micra (Cole) – BOLLI, 1957, U. S. Nat. Mus., Bull., no. 215, p. 161, pl. 35, figs. 1a–2b.

Occurrence: Lower and upper parts of Jacaguas group. In Trinidad this species ranges from the *Hantkenina aragonensis* assemblage zone of the Navet formation to the *Globorotalia cocoaensis* assemblage zone of the San Fernando formation.

Family ORBULINIDAE
Subfamily GLOBIGERININAE
Genus GLOBIGERINA d'Orbigny, 1826

Globigerina turgida Finlay
Plate 2, figures 3–5

Globigerina turgida FINLAY, 1939, Roy. Soc. New Zealand, Trans. Proc., vol. 69, p. 125. – BOLLI, 1957, U. S. Nat. Mus., Bull., no. 215, p. 162, pl. 35, fig. 13a–c; p. 73, pl. 15, figs. 3–5.

Occurrence: Lower and upper parts of Jacaguas group. In Trinidad this species ranges from the *Globorotalia aragonensis* assemblage zone, Lizard Springs formation, to the *Hantkenina aragonensis* assemblage zone of the Navet formation.

Globigerina sp. cf. **G. turgida** Finlay

Occurrence: Lower and upper parts of Jacaguas group.

Globigerina boweri Bolli
Plate 1, figures 11–13

Globigerina boweri BOLLI, 1957, U. S. Nat. Mus., Bull., no. 215, p. 163, pl. 36, figs. 1a–2b.

Occurrence: Lower and upper parts of Jacaguas group. In Trinidad this species occurs in the Navet formation and ranges from the *Hantkenina aragonensis* to the *Globigerapsis kugleri* assemblage zone.

PLATE 1

All figures × 105

1–3 *Globorotalia densa* (Cushman)
Umbilical, peripheral, and spiral views.

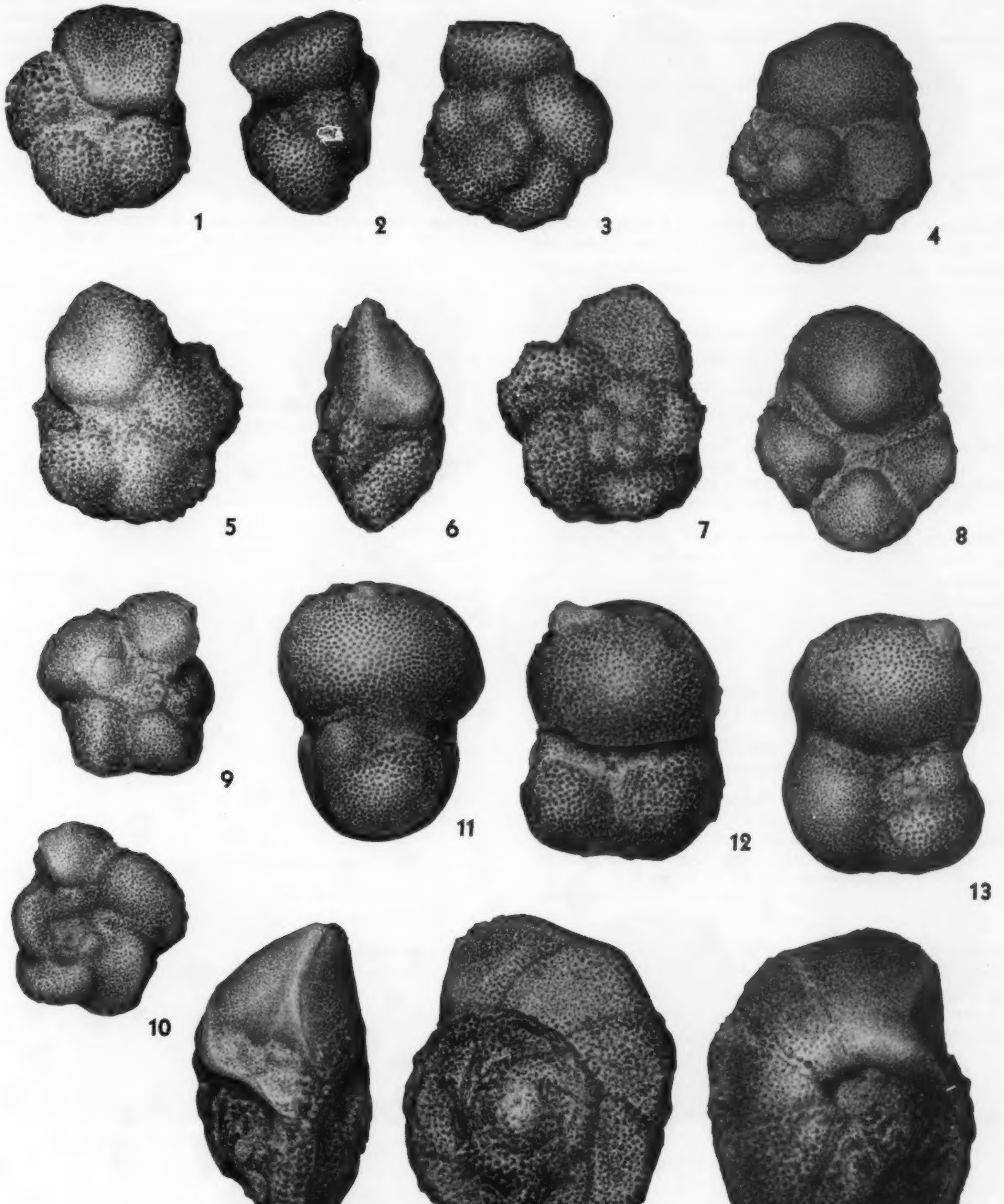
4, 8 *Globorotalia* sp. cf. *G. pseudomenardii* Bolli
Spiral and umbilical views.

5–7 *Globorotalia lehneri* Cushman and Jarvis
Umbilical, peripheral, and spiral views.

9–10 *Globorotalia spinuloinflata* (Bandy)
Umbilical and spiral views.

11–13 *Globigerina boweri* Bolli
Peripheral, umbilical, and spiral views.

14–16 *Globorotalia aragonensis* Nuttall
Peripheral, spiral, and umbilical views.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Globigerina sp. aff. **G. boweri** Bolli

Occurrence: Lower part of Jacaguas group.

Genus GLOBIGERINOIDES Cushman, 1927

"Globigerinoides" higginsi Bolli
Plate 2, figure 14

"Globigerinoides" higginsi BOLLI, 1957, U. S. Nat. Mus. Bull., no. 215, p. 164, pl. 36, figs. 11a–13b.

Occurrence: Lower and upper parts of Jacaguas group. In Trinidad this species ranges from the *Globorotalia palmerae* assemblage zone to the *Globigerapsis kugleri* assemblage zone of the Navet formation.

Subfamily ORBULINIDAE
Genus GLOBIGERAPSIS Bolli, Loeblich, and Tappan, 1957

Globigerapsis index (Finlay)
Plate 2, figures 15–17

Globigerinoides index FINLAY, 1939, Roy. Soc. New Zealand, Trans. Proc., vol. 69, pt. 1, p. 125, pl. 14, figs. 85–88.
Globigerapsis index (Finlay) – BOLLI, 1957, U. S. Nat. Mus., Bull., no. 215, p. 165, pl. 36, figs. 14a–18b.

Occurrence: Lower and upper parts of Jacaguas group. In Trinidad this species ranges from the *Globigerapsis kugleri* assemblage zone to the *Globigerapsis semiinvoluta* assemblage zone of the Navet formation. In Puerto Rico it sometimes occurs in the *Hantkenina aragonensis* assemblage zone (Chart 1, OP 229).

Family GLOBOROTALIIDAE
Genus GLOBOROTALIA Cushman, 1927

Globorotalia densa (Chushman)
Plate 1, figures 1–3

Pulvinulina crassata var. *densa* CUSHMAN, 1925, Amer. Assoc. Petr. Geol., Bull., vol. 9, p. 301.
Globorotalia crassata (Cushman) var. *densa* (Cushman) – CUSHMAN AND BARKSDALE, 1930, Stanford Univ., Contr. Dept. Geol., vol. 1, no. 1, p. 68, pl. 12, fig. 8.
Globorotalia densa (Cushman) – PESSAGNO, 1960, Micropaleontology, vol. 6, no. 1, p. 99, pl. 5, fig. 3.

Occurrence: Lower and upper parts of Jacaguas group. Cotui limestone member of the San German formation (?) (Pessagno 1960, pp. 80–92). *Globorotalia densa* occurs in the *Hantkenina aragonensis* and *Globigerapsis kugleri* assemblage zones of the Navet formation, Trinidad.

Globorotalia sp. aff. **G. densa** (Cushman)

Occurrence: Upper part of Jacaguas group.

Globorotalia spinulosa Cushman
Plate 2, figures 11–13

Globorotalia spinulosa CUSHMAN, 1927, Cushman Lab. Foram. Res., Contr., vol. 3, p. 114, pl. 23, figs. 4a–c. – BOLLI, 1957, U. S. Nat. Mus., Bull., no. 215, p. 168, pl. 38, figs. 6a–7c.

Occurrence: Lower and upper parts of Jacaguas group. In Trinidad this species ranges from the *Hantkenina aragonensis* assemblage zone to the *Porticulasphaera mexicana* assemblage zone. It occurs in the Navet formation.

Globorotalia broedermanni Cushman and Bermudez
Plate 2, figures 6–8

Globorotalia (Truncorotalia) broedermanni CUSHMAN AND BERMUDEZ, 1949, Cushman Lab. Foram. Res., Contr., vol. 25, pt. 2, p. 40, pl. 7, figs. 22–24.
Globorotalia broedermanni Cushman and Bermudez – BOLLI, 1957, U. S. Nat. Mus., Bull., no. 215, p. 80, pl. 19, figs. 13–15; p. 167, pl. 37, figs. 13a–c.

Occurrence: Lower and upper parts of Jacaguas group. In Trinidad this species ranges from the *Globorotalia rex* assemblage zone to the *Globigerapsis kugleri* assemblage zone, Navet formation.

Globorotalia aragonensis Nuttall
Plate 1, figures 14–16

Globorotalia aragonensis NUTTALL, 1930, Jour. Pal., vol. 4, no. 3, p. 288, pl. 24, figs. 7–8, 10–11. – BOLLI, 1957, U. S. Nat. Mus., Bull., no. 215, p. 167, pl. 38, fig. 1a–c.

Occurrence: Lower and upper parts of the Jacaguas group. In Trinidad this species ranges from the *Globorotalia formosa formosa* assemblage zone, Lizard Springs formation, to the *Globigerapsis kugleri* assemblage zone, Navet formation.

PLATE 2

All figures × 105

1–2 *Hastigerina micra* (Cole)
Peripheral and side views.

3–5 *Globigerina turgida* Finley
Peripheral, umbilical, and spiral views.

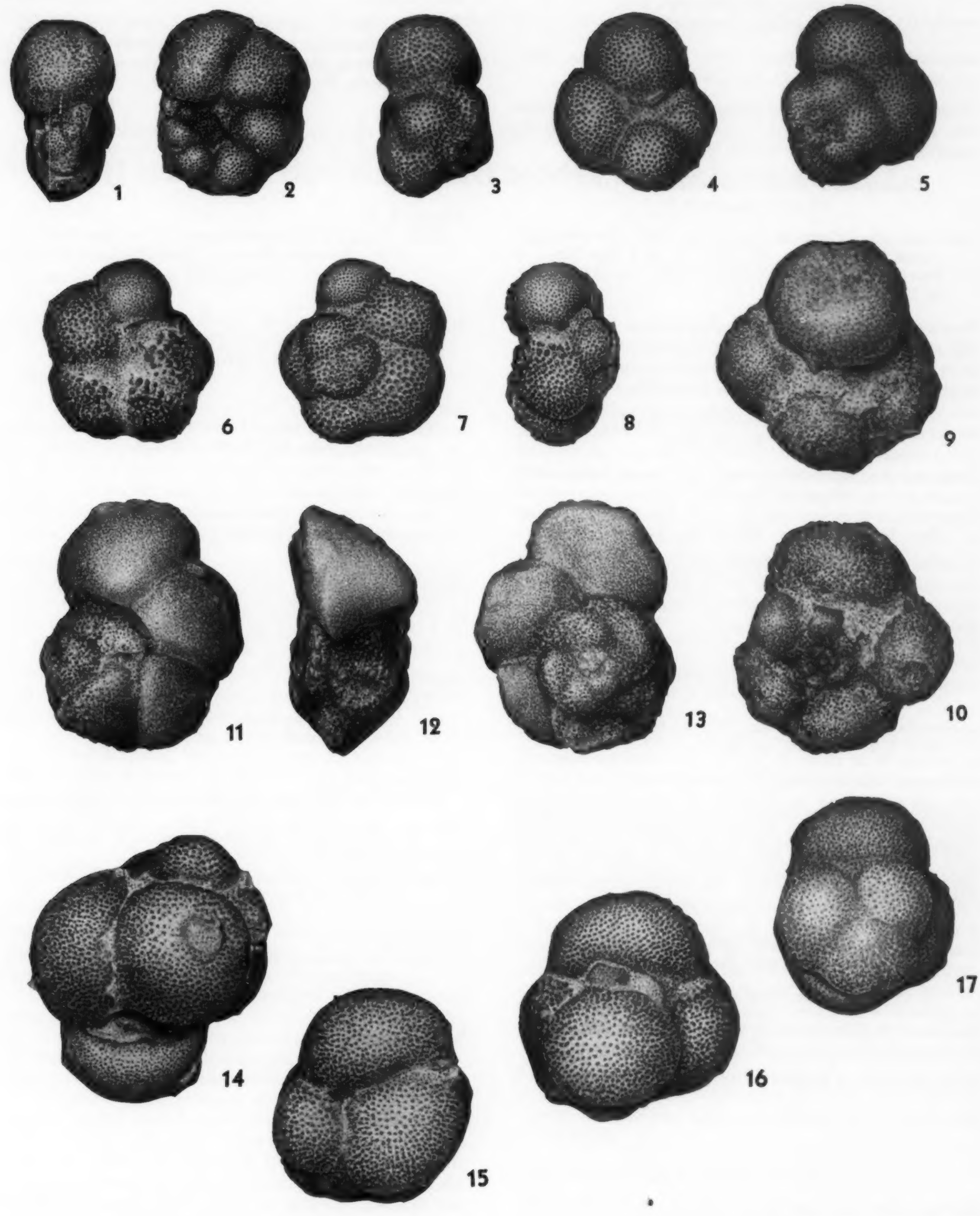
6–8 *Globorotalia broedermanni* Cushman and Bermudez
Umbilical, spiral, and peripheral views.

9–10 *Globorotalia pseudomayeri* Bolli
Umbilical and spiral views.

11–13 *Globorotalia spinulosa* Cushmann
Umbilical, peripheral, and spiral views.

14 *"Globigerinoides" higginsi* Bolli
Umbilical view.

15–17 *Globigerapsis index* (Finlay)
Side, umbilical, and spiral views. Umbilical view in figure 16 is from a different specimen.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Globorotalia pseudomayeri Bolli
Plate 2, figures 9–10

Globorotalia pseudomayeri BOLLI, 1957, U. S. Nat. Mus., Bull., no. 215, p. 167, pl. 37, fig. 17a–c.

Occurrence: Lower part of Jacaguas group. In Trinidad this species is restricted to the *Hantkenina aragonensis* assemblage zone of the Navet formation.

Globorotalia lehneri Cushman and Jarvis
Plate 1, figures 5–7

Globorotalia lehneri CUSHMAN AND JARVIS, 1929, Cushman Lab. Foram. Res., Contr., vol. 5, p. 17, pl. 3, figs. 16a–c. – BOLLI, 1957, U. S. Nat. Mus., Bull., no. 215, p. 169, pl. 38, figs. 9a–13.

Occurrence: Upper part of Jacaguas group. In Trinidad this species occurs in the Navet formation and ranges from the upper part of the *Globigerapsis kugleri* assemblage zone to the *Truncorotaloides rohri* assemblage zone.

Globorotalia spinuloinflata (Bandy)
Plate 1, figures 9–10

Globigerina spinuloinflata BANDY, 1949, Bull. Amer. Pal., vol. 32, no. 131, p. 122, pl. 23, fig. 1a–c.
Globorotalia spinuloinflata (Bandy) – BOLLI, 1957, U. S. Nat. Mus., Bull., no. 215, p. 168, pl. 38, fig. 8a–c.

Occurrence: Upper part of Jacaguas group. In Trinidad this species occurs in the Navet formation from the *Hantkenina aragonensis* assemblage zone to the *Porticulasphaera mexicana* assemblage zone.

Globorotalia sp. cf. **G. pseudomenardii** Bolli
Plate 1, figures 4, 8

Globorotalia pseudomenardii BOLLI, 1957, U. S. Nat. Mus., Bull., no. 215, p. 77, pl. 20, figs. 14–17.

Occurrence: Upper part of Jacaguas group.

Remarks: This species is quite similar to *G. pseudomenardii* Bolli, differing from it only by its straighter sutures dorsally and by possessing five chambers in the last whorl. Specimens were observed to be coiled both dextrally and sinistrally.

Family ANOMALINIDAE
Genus CIBICIDES Montfort, 1808

Cibicides micrus Bermudez

Cibicides micrus BERMUDEZ, 1949, Cushman Lab. Foram Res. Spec. Publ., no. 25, p. 302, pl. 24, figs. 34–36.

Occurrence: Lower part of Jacaguas group.

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ABSTRACT

Two new genera and five new species of ostracodes are described from the Middle Ordovician Bromide formation of Oklahoma. Distinctive dimorphism in these forms is also discussed.

New genera and species of Bromide (Middle Ordovician) ostracodes of Oklahoma

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INTRODUCTION

This paper, in which two new genera and five new species of Bromide (Middle Ordovician) ostracodes are described, supplements the monographic study by R. W. Harris (1957) of Simpson ostracodes of Oklahoma. The writer also discusses dimorphism observed in these forms and suggests some taxonomic changes in generic and specific assignments of Bromide ostracodes.

The ostracode species described here are from samples collected by the late W. Shideler of Miami University from the Middle Ordovician Bromide formation at Rock Crossing of Hickory Creek, sec. 35, T. 5 S., R. 1 E., in the Criner Hills, 6 miles southwest of Ardmore, Oklahoma. At this locality, which is the southwesternmost outcrop of the Bromide formation, 351 feet of Bromide is exposed beneath the Middle and Upper Ordovician Viola formation (Table 1); the entire thickness of the Bromide, however, is not represented here. The Bromide sediments in this area are predominantly argillaceous limestones which are very fossiliferous.

All type specimens have been deposited in the collections of the United States National Museum, Washington, D.C.

DIMORPHISM OF BROMIDE OSTRACODES

Dimorphism is conspicuous in two of the species of ostracodes described in this paper. Two adult forms (pl. 1, fig. 2a–e) of *Diplopsis socialis* Levinson, n. sp., were noted. One form has a convex frill along the ventral margin of the valve which extends to midheight at the anterior and posterior. The second form is unfrilled and possesses two short rows of spines on each valve. One row of spines begins at the postventral margin, and the other, at the anteroventral margin; they extend dorsally to a position which would mark the highest postdorsal extent of the frill. Because of the open nature of the frill when the valves are closed, it is doubtful whether the presence of the frill alone is conclusive evidence of the female dimorphic form. The young forms are unfrilled although the characteristic spines are found on molts of the youngest instars.

Eurychilina indivisa Levinson, n. sp., also possesses two mature forms (pl. 1, fig. 3c–d, f–g). One form has a wide frill which extends the length of the free margin; this frill bears a row of spines at its distal portion the length of the posterior free margin. These spines are commonly broken off and in the photomicrograph of this form are evident in the posterior area only. The other form, in addition to the wide frill, bears a "sausage-like" inflation which occurs along the entire length of the ventral margin and extends to one-half the height of the anterior. The frill is present at the distal portion of the inflation and on the free margins. Young specimens have a relatively wide frill extending the length of the free margins of the valve from the postdorsal to the anterodorsal margins.

In this fauna, as in other ostracode assemblages, it is common to find two groups of molts of a species, of which one group is more elongate than the other. It is also common, with exceptions, to find fewer elongate molts. Observations of typical living ostracode faunas confirm the generalization that the females outnumber the males and also show that the males are usually more elongate than the females. In species described here two groups of molts of one species are present with the more elongate molts occurring in fewer numbers. This is especially well shown in the new species *Saccelatia kellettae* Levinson (pl. 1, fig. 1b–c). The elongate forms are here designated as males, and the others, as females. It is believed that this practice is consistent with observations of living forms. It is doubtful whether the presence of so-called brood pouches alone are evidence of sexual dimorphism; their position commonly at the anterior portion of the shell, employing the now generally accepted orientation, adds uncertainty as to their true significance.

INNER-MARGINAL AREA IN BROMIDE OSTRACODES

The presence of a narrow inner-marginal area, extending from the postdorsal to the anterodorsal margin, was found on one specimen of *Bromidella reticulata* Harris,

TABLE 1

Bromide section at Rock Crossing of Hickory Creek in Criner Hills, 6 miles southwest of Ardmore, Oklahoma.

ZONE 11	I		3 ft. 3 in.	Massive limestone
	H		12 in.	Ostracodes abundant
	G		7 in.	Massive limestone
	F		5 in.	Ostracodes absent
	E	25 feet	10 in.	Ostracodes abundant
	D		2 ft. 7 in.	Ostracodes abundant
	C		12 ft. 6 in.	Ostracodes absent
	B		4 in.	Ostracodes abundant
	A		3 ft. 4 in.	Ostracodes absent
ZONE 10		15 in.		*Cliftonia gouldi* zone, ostracodes abundant
ZONE 9				Fossiliferous zone to *Cliftonia gouldi* zone
ZONE 8				Less fossiliferous limestone below bridge
ZONE 7				To top of massive and more resistant limestone exposed in creek bed below bridge
ZONE 6		325 feet		*Plaesiomys* sp. zone
ZONE 5				To *Plaesiomys* sp. zone
ZONE 4				Bryozoa zone, ostracodes abundant
ZONE 3				Thin, resistant limestone with intercalated shales with Bryozoa
ZONE 2				Resistant limestone below Bryozoa zone; limestone and shales
ZONE 1				Massive, resistant limestone below bridge

1931, and on one specimen of *Dicranella macrocarinata* Harris, 1931. The marginal area present is fairly wide at the venter for a Paleozoic form, and tapers as it nears the cardinal angles. This is believed to be the first report of an inner-marginal area on Ordovician forms. Because of the rarity of these specimens, however, it was not possible to prepare thin sections of them to ascertain whether the inner-margin coincides with the line of concrescence.

DESCRIPTION OF SPECIES

Order OSTRACODA LaTreille, 1802
Superfamily LEPERDITACEA Bassler and Kellett, 1934
Family APARCHITIDAE Ulrich and Bassler, 1923

Observation of species of the genus *Saccelatia* Kay and the new genus *Diplopsis* Levinson, typical members of the family Aparchitidae, has shown that one end of the carapace "fills out" with maturity; this end is called the posterior in the descriptions of species of these genera.

Genus **Saccelatia** Kay, 1940

Saccelatia KAY, 1940, Jour. Pal., vol. 14, no. 3, pp. 242–243, pl. 29, figs. 12–28.

Type species: Aparchites arrectus Ulrich, 1894 (by original designation); Geology of Minnesota, vol. 3, pt. 2, p. 646, pl. 43, figs. 35–36; Ion member, Decorah formation, St. Paul, Minnesota.

Description: Valves small to medium size, subovate; hinge straight, long, ends subequal; valves very convex, surface rises gently from dorsal margin to greatest thickness ventral to midheight; surface smooth, with pits or fine reticulation; rows of granules or spines commonly present on free margins; a dorsal spine may be present at the posterodorsal angle; ventral swellings, flanges, and projections found on some species. Dimorphism found in one species. Right valve usually larger than left and overlaps it the length of the free margins. Hingement unknown.

Occurrence: Middle Ordovician; Bromide formation of Oklahoma; Decorah formation of Minnesota and Iowa.

Saccelatia kellettae Levinson, **new species**
Plate 1, figure 1a–d

Description: Valves medium size, smooth, subovate; hinge depressed, straight, three-fourths length of valve; cardinal angles nearly equal, anterior slightly more obtuse; posterior margin slightly more convex than anterior; venter nearly parallel to dorsum rounding to cardinal angles. Surface rises from dorsum with the greatest thickness ventral to midheight. A row of spines, a short distance from edge of valve around the free margins on young forms; on mature specimens, spines absent near cardinal angles; spines always more prominent on left valve, may be entirely absent on right valve. Males more elongate than females. Prominent short outward-pointing spine present near postdorsal margin of left valve of female (one young female found with an additional anterodorsal spine); dorsal spine absent on males. Right valve slightly larger than left and overlaps it around the free margins. Faint reticulations found on two specimens. Hingement unknown.

Occurrence: Zone 11b, abundant; zone 10, common; zone 11d, frequent; zone 11a, frequent; zone 11h, abundant; Bromide formation of Oklahoma.

Dimensions: Holotype, double valve, female, length 1.45 mm., height 0.93 mm., width 0.73 mm. Paratype, double valve, female, length 0.64 mm., height 0.44 mm., width 0.35 mm. Paratype, double valve, male, length 1.28 mm., height 0.77 mm., width 0.62 mm.

Types: Holotype USNM no. 139576; paratypes USNM no. 139577 and no. 139578.

Remarks: This species very closely resembles *Saccelatia arrecta* (Ulrich) but can be differentiated from it by the presence of the prominent posterodorsal spine on the female and the marginal spines which are always more prominent on the left valve.

This form resembles *Hyperchilarina nodosimarginata* Harris, 1957; adults, however, are smaller, 1.4 mm. in contrast to 2.0 mm. *Saccelatia kellettae* possesses a postdorsal spine and the left valve does not project above the hinge line.

It is surprising that, whereas over one hundred specimens of this species were found, only three single valves were noted, the remainder being complete carapaces. There is possibly some significance in this occurrence because, with other species in the same zones, complete carapaces are rare.

Genus **Diplopsis** Levinson, **new genus**

Type species: Diplopsis socialis Levinson, n. sp.; Zone 11e, Bromide formation, in Criner Hills of Oklahoma.

Description: Carapace of medium size, subtrapezoidal to subovate; hinge long, straight, slightly depressed; cardinal angles rounded; posterior margin slightly more convex than anterior; greatest thickness slightly below midheight. Two mature forms present; one form possesses a convex frill which generally conforms with the convexity of the surface; the frill extends to almost midheight at the anterior and posterior. An unfrilled form possesses a low marginal ridge from the postdorsal to anterodorsal margins; two rows of short spines are present on the ridge, one starting at the postventral margin and the other at the anterodorsal margin; they extend to a midheight position, which would mark the highest postdorsal and anterodorsal extent of the frill. Left valve larger than right and internally beveled the length of the free margins; right valve has outer beveling. Hingement of right valve consists of a groove the length of the dorsal margin. Hingement of left valve consists of a ridge the length of the dorsal margin.

Occurrence: Middle Ordovician; Bromide formation of Oklahoma.

Remarks: Opikella Thorslund from the Upper Ordovician of Sweden somewhat resembles the new genus *Diplopsis*, but differs in the angularity of the cardinal angles, the restriction of the frill to the venter and anteroventral margin, and the absence of spines. Thorslund (1940, p. 181) places the genus *Opikella* in the family Kirkbyidae Ulrich and Bassler, which is obviously incorrect; it is believed that *Opikella* should be included in the Aparchitidae.

The closest related species of *Diplopsis socialis* Levinson (the type species) is *Primitia maccoyii* Jones and Holl from the Caradoc (Lower Silurian?) of Ireland. Only an unfrilled form of this species has been described which resembles *D. socialis* in dorsal and ventral view and overlap; however, there is an absence of the anterior and posterior spines. *Primitia maccoyii* may possibly be a species of the new genus *Diplopsis*.

Diplopsis socialis Levinson, **new species**
Plate 1, figure 2a–e

Aparchites maccoyii (Salter) Jones, 1893 [sic]. – Harris, 1957, Okla. Geol. Surv., Bull. 75, pp. 138–140, pl. 2, figs. 2a–c, 3a–b, 4.

Description: Carapace of medium size, subtrapezoidal to subovate; hinge long, straight, slightly depressed; cardinal angles rounded; posterior margin slightly more convex than anterior, venter gently arcuate; greatest thickness slightly below midheight. Two mature forms present; one form possesses a convex frill which generally conforms with the convexity of the surface; the frill extends to almost midheight at the anterior and posterior. An unfrilled form possesses a low marginal ridge from the postdorsal to anterodorsal margins; two short rows of spines are present on the ridge. One row starts at the postventral margin and the other at the anteroventral margin; they extend dorsally to a position midheight which would mark the highest postdorsal and anterodorsal extent of the frill; the posterior spines increase in size ventrally and are always larger than the anterior spines. The young forms are unfrilled and the characteristic spines are found on molts of the youngest instar. Left valve larger than right. Right valve externally beveled the length of the free margins; left valves internally beveled the length of the free margins, the beveling becoming more prominent as it nears the dorsal margin. Closure of valves at true ventral margin with the edges of the frill agape (pl. 1, fig 2e); true ventral margin of mature left valve forms a liplike extension to receive the extended venter of the right valve. Hingement of right valve consists of a groove the length of the dorsal margin. Hingement of left valve consists of a ridge the length of the dorsal margin.

Occurrence: Zone 11e, abundant; 11b, abundant; 11d, common; 10, common; Bromide formation of Oklahoma.

Dimensions: Holotype, left valve, frilled, length 1.39 mm., height 0.90 mm., width 0.50 mm. Paratype, right valve, frilled, length 1.31 mm., height 0.925 mm., width 0.485 mm. Paratype, right valve, unfrilled, length 1.04 mm., height 0.703 mm., width 0.23 mm.

Types: Holotype USNM no. 139579; paratypes USNM no. 139580 and no. 139581.

Superfamily Beyrichiacea Ulrich and Bassler, 1923
Family Bassleratiidae E. A. Schmidt, 1941

Genus **Saturnites** Levinson, **new genus**

Type species: Saturnites harrisi Levinson, n. sp.; Zone 11e, Bromide formation, in Criner Hills of Oklahoma.

Description: Carapace small, subrectangular; hinge long, straight; a ridge parallels free margins and dorsal margin outlining the valve; a median ridge extends from the dorsum to the venter dividing the valve into two portions, the anterior portion being larger than the posterior; node in anterior portion, slightly raised area in posterior.

Occurrence: Middle Ordovician; Bromide formation of Oklahoma.

Remarks: This genus somewhat resembles the genus *Bassleratia* Kay, but differs in having fewer ridges and a median ridge which divides the valve into two portions.

Saturnites harrisi Levinson, **new species**
Plate 1, figure 6

Description: Carapace small, rectangular; hinge long, straight; cardinal angles appear equal; venter nearly straight, parallel to dorsal margin, slightly concave at median position; anterior margin slightly more convex than posterior. A marginal ridge outlines the entire free margins and dorsum of the valve and projects slightly above dorsum at anterior; a median ridge extends from the dorsum to the venter dividing the valve into two portions, the anterior portion larger than the posterior, the median ridge concave anteriorly. The anterior portion within the ridges is slightly raised with a small prominent node slightly posterior to the median part of the area; the posterior portion is usually slightly inflated but lacks a distinct node. Hingement unknown.

Occurrence: Zone 11e, rare (two single valves found); Bromide formation of Oklahoma.

Dimensions: Holotype, left valve, length 0.455 mm., height 0.268 mm., width 0.106 mm.

Types: Holotype USNM no. 139582.

Family Eurychilinidae Henningsmoen, 1953

Genus **Eurychilina** Ulrich, 1889

Eurychilina Ulrich, 1889, Canada Geol. Surv., Contr., pt. 2, p. 52, pl. 9, fig. 9a.

Type species: Eurychilina reticulata Ulrich, 1889 (by original designation); Canada Geol. Surv., Contr., pt. 2, p. 52, pl. 9, fig. 9a; Guttenberg member, Decorah formation, Fountain, Minnesota.

Description: Valves medium to large size, subequal; hinge long, straight; surface regularly convex with a distinct median to anterodorsal sulcus and a rounded node at the anterior margin of the sulcus; a broad to narrow striate frill of varying character present; surface coarsely reticulate, pitted, papillose, or smooth. Dimorphism sometimes present, represented by a "sausage-like" inflation at venter on mature forms.

Occurrence: Lower Ordovician to Lower Silurian of North America and Europe.

Eurychilina indivisa Levinson, **new species**
Plate 1, figure 3a–g

Description: Valves medium to large size, subquadrate to subovate; cardinal angles equal; anterior and posterior free margins equally convex, venter nearly parallel to dorsum; anterodorsal sulcus extends to nearly one-half the height of the valve, prominent rounded node forms anterior margin of the sulcus. There are two mature forms present. One form possesses a wide frill which extends the length of the free margins and bears a row of spines at the distal portion of the frill the length of the posterior free margin; the frill is commonly finely striate perpendicular to the frill margin. The other form possesses a "sausage-like" inflation the length of the ventral margin and extends to one-half the height of the anterior; a wide frill is present at the distal portion of the inflation and the other free margins; the inflation actually occupies a portion of the frill; the form with the inflation bears the posterior spines and the striations on the frill and inflation. The young form possesses a relatively wide frill around the free margins of the valve with the node not as prominent as on the mature forms and the sulcus in a more median position. Surface smooth on young molts; widely spaced papillae commonly cover the surface of the mature forms. Hingement of right valve consists of a groove the length of the dorsal margin. Hingement of left valve consists of a ridge the length of the dorsal margin with a thin groove ventral

PLATE 1

1 *Saccelatia kellettae* Levinson, n. sp.
1a, left valve, female, holotype, zone 11b, × 25
1b, right valve, same specimen as above, × 25;
1c, left valve, male, paratype, zone 11b, × 25;
1d, left valve, young, paratype, zone 11b, × 35.

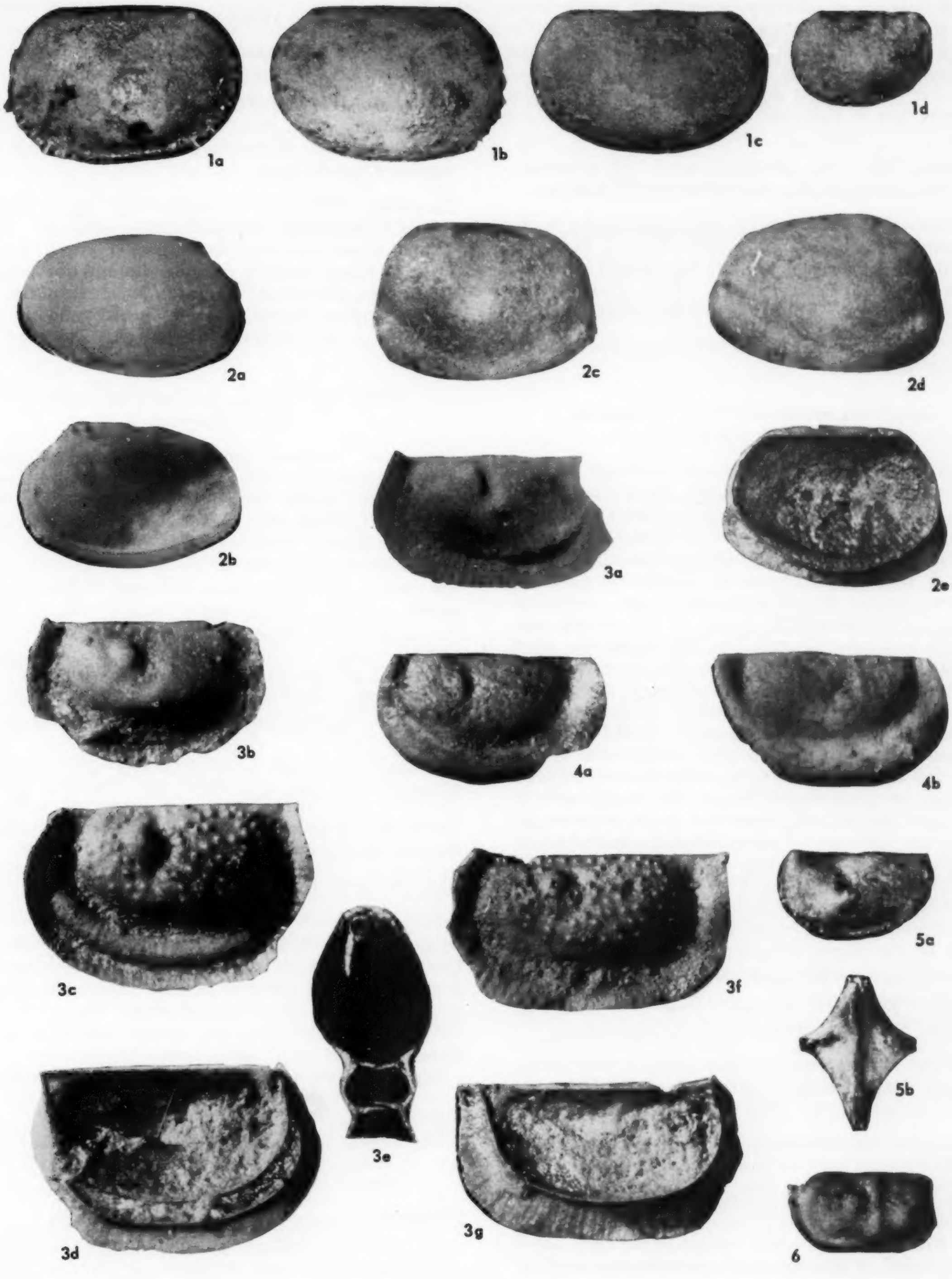
2 *Diplopsis socialis* Levinson, n. g., n. sp.
2a, right valve, exterior, male, paratype, zone 11e;
2b, same specimen as above, interior view;
2c, left valve, female, holotype, zone 11d;
2d, right valve, female, paratype, zone 11e;
2e, left valve, female, holotype, interior view. All × 25.

3 *Eurychilina indivisa* Levinson, n. sp.
3a, left valve, female, zone 11h, × 25;
3b, left valve, young, zone 11h, × 25;
3c, left valve, external view, female, holotype, zone 11h, × 20;
3d, same specimen as above, internal view, × 20;
3e, thin section of female complete carapace, zone 11h, × 30;
3f, left valve, external view, male, paratype, zone 11 h, × 20;
3g, same specimen as above, internal view, × 20.

4 *Eurychilina werneri* Levinson, n. sp.
4a, left valve, paratype, zone 11d, × 20;
4b, right valve holotype, zone 11d, × 20.

5 *Winchellatia nasutus* Levinson, n. sp.
5a, left valve, holotype, zone 11b, × 35.
5b, same specimen, dorsal view, × 35.

6 *Saturnites harrisi* Levinson, n. g., n. sp.
Left valve, holotype, zone 11e, × 50.


1a
1b
1c
1d
2a
2c
2d
2b
3a
2e
3b
4a
4b
3c
3e
3f
5a
5b
3d
3g
6

to the ridge. Area of interior postdorsal and anterodorsal margins very shallow, but steepens rapidly away from the margins. Right valve overlaps the left at the venter in both the frilled and pouched forms; in the pouched form (pl. 1, fig. 3e), however, the extension of the valve forming the dorsal limit of the pouch also overlaps, but in this case, the left valve overlaps the right.

Occurrence: Zone 11h, abundant; zone 11d, abundant; zone 11e, abundant; Bromide formation of Oklahoma.

Dimensions: Holotype, left valve, pouched form, length 2.48 mm., height 1.29 mm., width 0.47 mm. Paratype, left valve, frilled form, length 1.87 mm., height 1.06 mm., width 0.34 mm. Paratype, left valve, young form, length 1.13 mm., height 0.75 mm., width 0.23 mm.

Types: Holotype USNM no. 139583; paratypes USNM no. 139584 and no. 139585.

Eurychilina werneri Levinson, new species
Plate 1, figure 4a–b

Description: Valves of medium size, subovate to subquadrate, cardinal angles usually equal; prominent anterodorsal sulcus extends to nearly one-half the height of the valve; a faint elongate node forms anterior margin of the sulcus; frill of left valve different from that of right. The left valve has a very wide frill extending around the free margins; flat at anterodorsal area, convex at venter, flaring outward at posterior; frill slightly narrower at anterodorsal area. The frill of the right valve extends around the free margins; flat at anterodorsal area, convex at venter; this frill is distinctly narrow and diagonally straight at the postventral margin; a row of spines is present at the distal portion of the frill at this postventral margin. Another form present has a narrower frill around free margins, of equal width on both valves; right valve has the diagonally straight area at postventral margin with the row of spines extending to venter. On right valve of young forms, the spines extend to midway the length of the venter, the sulcus is only slightly anterior and the frill fairly wide. Surface smooth with widely scattered small pits or coarse pores. Hingement of right valve consists of a distinct groove the length of the dorsal margin. Hingement of the left valve consists of a ridge the length of the dorsal margin.

Occurrence: Zone 11d, frequent; zone 11h, common; zone 11e, rare; Bromide formation of Oklahoma.

Dimensions: Holotype, right valve, length 1.64 mm., heigth 0.94 mm., width 0.23 mm. Paratype, left valve length 1.65 mm., height 0.94 mm., width 0.23 mm.

Types: Holotype USNM no. 139586; paratype USNM no. 139587.

Remarks: E. werneri is distinguished from other species of *Eurychilina* by the narrow, diagonally straight portion of the frill at the postventral margin of the right valve with the frill of the left valve of uniform convexity throughout its length.

Family Incrertae Sedis

Genus Winchellatia Kay, 1940

Winchellatia Kay, 1940, Jour. Pal., vol. 14, no. 3, pp. 253–254, pl. 32, figs. 1–5.

Type species: Winchellatia longispina Kay, 1940 (by original designation); Jour. Pal., vol. 14, no. 3, pp. 253–254, pl. 32, figs. 1–5, Guttenburg member, Decorah formation, Church, Iowa.

Description: Valves small to medium size, equal. Outline subovate to subrhomboidal; hinge straight, long; distinct sulcus anterior to center of valve with a rounded node or slight inflation forming the anterior margin. Dimorphic, postventral margin in female form bearing flange or spine, typically serrate. Surface smooth, may have spines on anterior. Internal characteristics unknown.

Winchellatia nasutus Levinson, new species
Plate 1, figure 5a–b

Description: Carapace small, apparently equivalved; hinge long, straight; anterocardinal angle more obtuse; anterodorsal angle extends slightly above dorsum; venter almost parallel to dorsum gently curving to cardinal angles. A prominent anterior submedian ventral spine points away from the shell and curves to the posterior; a well-defined elongate sulcus-like pit present just dorsal to the base of the spine not extending to the dorsum; a small inflation present at the anteroventral margin of the sulcus-like pit. A row of well-developed papillae is present along the length of the free margins, slightly smaller at posterior. Internal characteristics unknown, only complete carapaces found.

Occurrence: Zone 11b, rare; zone 11d, rare; Bromide formation of Oklahoma.

Dimensions: Holotype, double valve, length 0.64 mm., height 0.36 mm., width 0.59 mm.

Type: Holotype USNM no. 139588.

Remarks: Although the spine is similar to that found in *Aechmina*, the position of the spine near the venter and the presence of a pitlike sulcus distinguish this species from those of that genus.

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ABSTRACT

Changes in diversity of fossil polospore assemblages, traced through sedimentary series, are interpreted as having evolutionary and environmental significance in terms of the floras that produced them. Congruent corresponding changes in the frequency of first and last appearances lend support to these hypotheses. Paleobotanical remains and the physical history of the region, as deciphered directly from the sediments, are other sources of supporting evidence. Data from three comprehensive publications dealing with the description and stratigraphic distribution of fossil polospores are analyzed by this approach.

Palynology, paleofloras and paleoenvironments

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INTRODUCTION

The success of Quaternary pollen study is directly related to the ability to assign these fossils to modern botanical equivalents. This fact makes possible the direct use of modern phytoecology in paleoecologic and climatologic analysis.

With increasing geologic age, fossil microfloras are less amenable to this approach. Evolution of floras over geologically significant time increases the subjectivity inherent in the purely botanical approach to pollen analysis. This uncertainty is roughly proportional to the antiquity of the microflora being analyzed.

Traverse (1955), in describing a microflora of possibly upper Oligocene to lower Miocene age, from the Brandon lignite of Vermont, found that 19 of 56 generic entities having dicotyledonous affinity could not be assigned generic names. Of 76 distinct fossil spore and pollen types, 13 could not be assigned to known families, and 49 required new specific assignments.

Steeves (1959) described about 200 distinct fossil polospore types from the subsurface Cretaceous of Long Island. None were referred to modern species. Only a small proportion of the grains described could be related to living genera. In part, this may be due to our incomplete knowledge of extant pollen types. However, many of these fossils undoubtedly belong to extinct groups.

It is obvious that methods supplementing the purely botanical approach would be helpful for palynologic analysis of the geologically older microfloras.

BIOTIC DIVERSITY AND ENVIRONMENTS

Fischer (1960) recently stated that biotic diversity is a product of evolution, and is dependent upon the length of time through which a given biota has developed in an uninterrupted fashion. Equable, little-changing subtropical and tropical environments permit evolutionary processes to develop great floral and faunal diversity. It is axiomatic that such environments are characterized by relatively large numbers of animal and plant species. Conversely, severely limiting environments exercise maximum selectivity, limiting biotic diversity. Such environments are characterized by relatively few species. Fischer illustrates this effectively by presenting diversity gradients as functions of latitudinal difference, for several unrelated organisms.

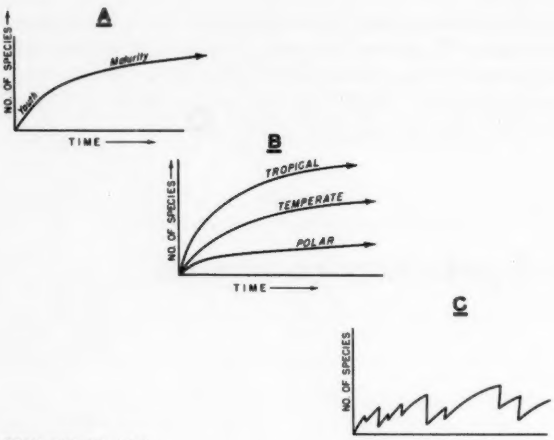
Fischer further projects hypothetical organic diversity curves as functions of time. In geographic settings, uninfluenced by climatic change, organic diversity curves correspond to biotic maturity curves. Different parts of this curve correspond to different degrees of biotic maturity (text-fig. 1A).

Postulating these curves for different latitudes would result in a faster rising curve in the tropics than in temperate latitudes, with the slowest rise in the polar latitudes (text-fig. 1B).

With climatic fluctuations, variability in the time factor is involved as well (text-fig. 1C). According to Fischer, "Some biotas have reached greater diversification because of steady evolution over greater periods of time; others have originated later or been subject to periodic decimations resulting in an irregular organic diversity curve."

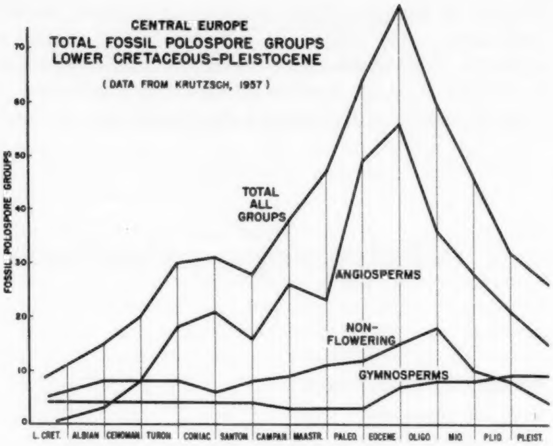
In order to apply this type of analysis to the study of fossil organisms, it is necessary to have a continuous and comprehensive record of their stratigraphic distribution for the areas being investigated. Principal limitations of palynologic data are:

1) The incompleteness of these data for many geographic areas and stratigraphic series.



FROM FISCHER, 1960

TEXT-FIGURE 1



TEXT-FIGURE 2

2) Interpretational difficulties connected with assigning unit taxa to form genera and species. This may seriously bias estimates of biotic diversity resulting from uneven systematic splitting and lumping.

3) Differences in interpretation of stratigraphic equivalence. These may operate to put "out of phase" data that could have significance, in proper stratigraphic context.

However, fairly comprehensive and well-documented compilations of the stratigraphic distribution of fossil polospores are available for portions of the geologic column in certain areas. Preliminary results of analyses of these data, in terms of biotic diversity, show interesting parallels with independent evidence concerning paleoenvironmental changes and floral evolution.

TERTIARY MICROFLORAL DIVERSITY

Dorf (1955) has summarized the Tertiary floral evidence for progressive climatic deterioration. In western North America, southeastern United States and northwestern Europe, the data suggests that maximum temperatures were attained in the late Eocene epoch. Progressive cooling and drying, beginning in the Oligocene, resulted in progressive replacement of dominantly tropical floras by temperate floral associations. The same climatic trend has been inferred from the study of successive marine faunas of the west coast of the United States, the marine invertebrate succession of northwestern Europe, and by the character of changes in the Tertiary vertebrate record.

Dorf also indicates the relative proportions of genera composing plant groups for the successive Cretaceous floras of the eastern United States. Lower Cretaceous angiosperms are still markedly subordinate to fern, cycad, and conifer genera. The Albian and Cenomanian show a rapid increase in angiosperm genera, while in the Turonian they have become the dominant floral element.

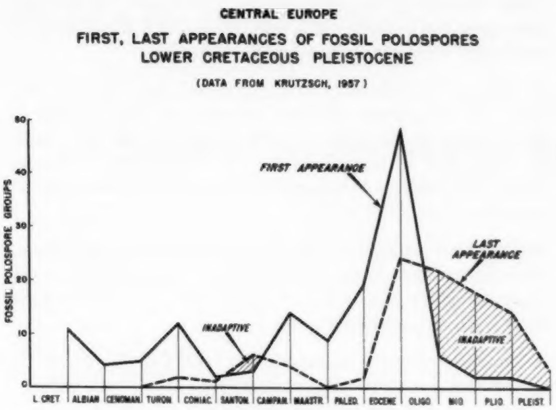
Krutzsch (1957) has compiled a summary of the stratigraphic distribution of fossil polospores in central Europe, ranging from the Lower Cretaceous to the Pleistocene. Plotting his data as total frequency of fossil polospore groups for the successive stages results in marked parallels with paleobotanical data.

The interpolated curve (text-fig. 2) which may be assumed to be an approximate record of floral diversity for this area during the indicated geologic time span, shows progressive increase from the Lower Cretaceous through Turonian, a leveling off and slight reduction during the Coniacian—Santonian, and then rapid increase to an Eocene maximum. Sharp reduction follows in the Oligocene, with continuing reduction through the remainder of the Tertiary.

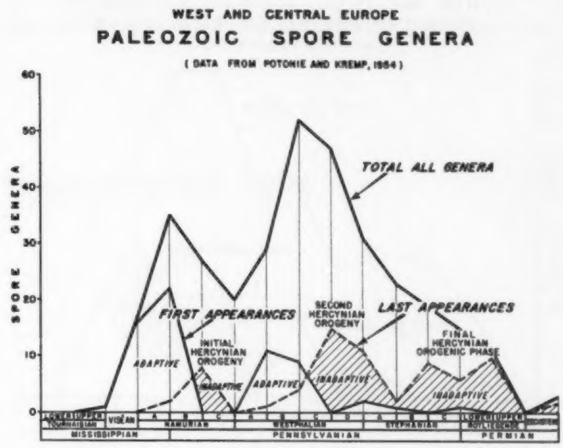
This is essentially an angiosperm record as little is contributed to the over-all pattern by the non-flowering plants and the gymnosperms.

Interestingly enough, the angiosperm diversity curve first shows distinct dominance over other plant groups in the Turonian, just as Dorf indicates on paleobotanical evidence.

Plotting only frequencies of first and last appearances, irrespective of plant groups (text-fig. 3), shows that last appearances exceed first appearances during the Santonian, and again from the Oligocene to the end of the Tertiary. The Coniacian—Santonian diversity reduction has been noted in other fossil organisms as well. Bronnimann and Brown (1956) note that Cretaceous pelagic foraminifera (Globotruncanidae) are represented by seven distinct generic types in the upper Cenomanian—lower Turonian. Only two continue through the Coniacian—Santonian, while during the Campanian—Maes-



TEXT-FIGURE 3



TEXT-FIGURE 4

trichtian pelagic foraminifera attained another diversification peak. It is possible that a general reduction in mean annual temperatures during the Coniacian—Santonian may have been a contributing factor in these diversity reductions, but other positive evidence for this is not yet available. The large number of last appearances from the Oligocene to the Recent certainly fit the progressive climatic deterioration of the Tertiary, already suggested by many workers.

PERMO-CARBONIFEROUS MICROFLORAL DIVERSITY

Potonié and Kremp (1954) have compiled the known stratigraphic distribution of Paleozoic spores (Permo-Carboniferous) for Eurasia, Europe, and North America. The data for western and central Europe apparently are the most complete, and are therefore chosen here for analysis. Using Potonié and Kremp's data, frequency curves of Paleozoic spore genera have been plotted for the successive stages from the Tournaisian through the Zechstein (text-fig. 4).

The European curve is markedly bimodal with rapid increase from the Tournaisian to the Viséan followed by marked reduction through the Namurian. The Westphalian shows rapid increase to a peak in the Westphalian B. Thereafter reduction is continuous to almost complete extinction of the Carboniferous microfloral elements in the upper Rotliegende (Middle Permian or Autunian). The Zechstein shows a slight increase, again reflecting the first European appearance of many typically Permian microfloral elements.

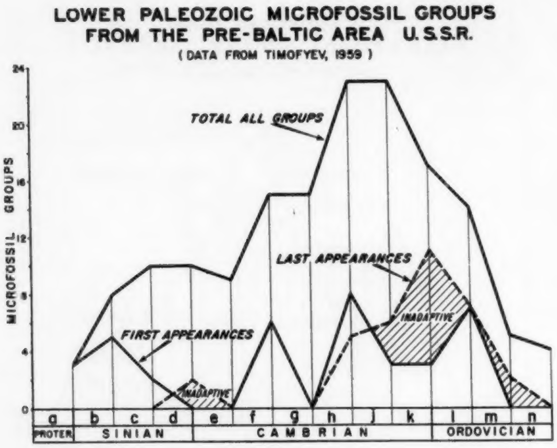
Plotting frequencies of first and last appearances from the same data results in first appearance peaks in the Viséan—lower Namurian and the lower to mid-Westphalian. These are interpreted as periods of prevailingly adaptive environments during which biotic diversity peaks were attained.

Last appearance peaks are markedly asymptotic to the first appearance peaks, occurring in the Namurian, upper Westphalian, mid-Stephanian, and lower Rotliegende.

The physical history of western and central Europe during the Permo-Carboniferous (Gignoux, 1955, chapter 5) indicates that the first Hercynian orogenic phase occurred during the Namurian, leaving its record in folding in the Saar basin, Brittany, the Vosges, the French Central Massif, and the Pyrenees. Flysch facies are predominant in Great Britian (the Millstone grit) and in the Franco-Belgian basin. A secondary Hercynian orogeny is recorded during the upper Westphalian by intense folding in the Saar basin, Franco-Belgian basin, Spain, the Vosges, the French Central Massif and the Carnic Alps. Hiatuses and disconformities are common in the upper Westphalian (Mercean) of Great Britian.

In many places the Stephanian is missing entirely or represented by continental facies. A final Hercynian orogeny is recorded during the Autunian (upper Rotliegende) in the Franco-Belgian basin, the Saar basin, and in the Urals.

The periodicity of the Hercynian movements seem to be in close agreement with the last appearance maximae based on the fossil polospore record. In addition, the relative orogenic inactivity of the Viséan—lower Namurian, and again in the lower Westphalian, coincides with the first appearance maximae of the fossil polospore record. Climatic diversification, including increased temperature and humidity gradients, may be assumed to have resulted from each of the Hercynian orogenic periods that created inadaptive parameters for many floral elements. Conversely, during intervening periods the uniform environments resulted in maximum biotic diversification.



TEXT-FIGURE 5

PRE-CAMBRIAN—LOWER PALEOZOIC MICROFLORAL(?) DIVERSITY

As a last example of the biotic diversity method of microfloral analysis, data are used from a study by Timofeev on the microflora of the pre-Baltic area. This microflora was found in the sedimentary succession on the northwest Russian boundary of the Baltic Shield, and includes Pre-Cambrian, Sinian (infra-Cambrian), Cambrian, and Ordovician strata.

The incertae sedis elements were placed in 36 form-genera and included in six larger groups. Many of these have been previously described as belonging within that diversified group of organisms known as hystrichosphaerids, by Eisenack, Deflandre and others.

Obviously, a biologic interpretation of such ancient microfossils, based on taxonomic affinity to modern groups, would be useless. However, an analysis of their stratigraphic record, in terms of biotic diversity, yields interesting results that have some parallel with the physical geologic record of this region. The total frequency curve attains a Cambrian peak, which is progressively reduced from the Mid-Cambrian through the Middle Ordovician (text-fig. 5). First appearances show peaks in the Lower Sinian, Lower and Mid-Cambrian, and Lower Ordovician.

No first appearances, but some last appearances may indicate inadaptive conditions at the Upper Sinian—Cambrian transition. Last appearances exceed first appearances markedly from the Mid-Cambrian to Lower Ordovician, indicating inadaptive environments. Complete replacement of the older elements resulted within this time.

Krivtsov (1958) has summarized the latest stratigraphic data on this region. He finds that the Sinian and Lower Cambrian formations are characteristic of a littoral marine environment with very unstable shorelines. From Mid-Cambrian time on, the sea was regressive and a vast stretch of northwestern European U.S.S.R. stood high. It was during this regressive phase that the Cambrian microflora became extinct. The Lower Ordovician transgression brought in a new microflora that replaced the older elements completely.

In summary, it should be emphasized that this is a first attempt at analysis of fossil palynologic data solely in terms of biotic diversity. Conclusions reached here must be regarded as tentative. As additional data become available, these conclusions will be further substantiated or will require alteration.

At this time, it appears that these tentative conclusions have more than random correlation with similar conclusions based on the study of other fossil groups, and on the physical geologic record.

Acknowledgment is made to the Gulf Oil Corporation for permission to publish this paper.

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ABSTRACT

A technique in the preparation of scolecodonts for study under the microscope is described. Possible application of this technique in the study of other microfossils is indicated.

Study of scolecodonts by transmitted light

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INTRODUCTION

Much of the literature on scolecodonts (Eller, Stauffer, et al.) is illustrated by drawings. Subjective factors are thus introduced. For example, shading and thickness of lines might mislead a taxonomist in the process of describing new material. Even when excellent photographs have been used (Sylvester, 1959), the specimens are first coated white to aid reflection of light, and subsequently the photographs are retouched to bring out salient details.

A recently discovered assemblage of Leonardian scolecodonts (Tasch and Stude, 1960; and, in preparation) confronted the senior author with some of the these problems. Several experiments were undertaken in an effort to resolve them.

Scolecodonts are normally dense, black or brownish-red opaque objects. When illuminated for photography, the rays of light are partly absorbed and the remaining rays reflected imperfectly. The glare that results obscures scolecodont surface details on the photograph. The junior author suggested that commercial Clorox might bleach the scolecodonts and, that, in turn, could reduce the glare. If bleaching could be realized, that would simulate coating the specimens with a white metallic powder, and improved reflection of the incident light might be expected. To determine just what the Clorox treatment might do, a rather simple experiment was tried. The surprising results are described in this note. Photographs were taken by Don Dalrymple.

OXIDATION TECHNIQUE

A scolecodont to be photographed was placed on a cover slip. One drop of commercial Clorox was placed on the specimen. The preparation was then let stand for a few minutes. From time to time the Clorox was replenished. After ten-to-twenty minutes, inspection showed that the organic material darkening the denticles had disappeared. However, the specimen had not been bleached. Instead, the denticles now appeared amber-colored, and the entire specimen had become translucent.

Several additional specimens were treated individually. It was found that at least three factors controlled the time necessary to achieve translucence. These were: the size, thickness of the specimen, and the amount of contained organic material. Experiments to date indicate that larger and relatively thicker scolecodonts such as *Arabellites hamiltonensis* (Stauffer) may not be completely oxidized even after many hours of Clorox treatment. However, in such cases, it was found that different parts of the specimen do become translucent, such as the fang tip and the periphery of the scolecodont. Furthermore, one must observe caution in the use of undiluted Clorox. In some instances, denticles, fang tips, or other parts of the specimen, may be completely digested. Experiments are under way to determine suitable dilutions of Clorox to be used with specimens of varying size and thickness.

The reaction is not visible. Under high power, minute bubbles may be found around parts of the scolecodont. The action is silent, slow, and may mislead the investigator into thinking that nothing is happening. In that event, the preparation should be permitted to stand as long as necessary – several hours if needed–always replenishing the evaporating pool of Clorox on the slide.

A side-effect was also observed. The active component of commercial Clorox is sodium hypochlorite (5.25 percent by weight). If the Clorox pool is permitted to evaporate completely in a Petri dish, which offers a wide evaporating surface area, pyramidal hopper crystals will form. On the other hand, the Clorox pool of one or a few drops on a cover slip, if permitted to evaporate, will form a mesh of non-cubic crystals. It was found desirable to prevent the formation of crystals, which can exert a bursting pressure during growth. This can be achieved by frequent inspection of the specimen on the cover slip. The rate of the reaction can be slowed down at any time by the addition of a drop or two of water.

MOUNTING

When the scolecodont has become completely translucent, the remaining Clorox is blotted or removed by a capillary dropper. A commercial preparation, Clearcol, which is water soluble, is spread over the specimen. It should be noted that the scolecodont must not be moved or transferred on the cover slip, nor exposed to strong light, as the oxidizing process has made it relatively fragile, and the specimen might crack or break.

Once the mounting medium has hardened, the glass slide can be prepared with Diaphane or any other suitable mounting medium. Firmly held in place on the cover slip, the scolecodont can next be inverted. The whole slip, gently pressed down into the Diaphane, will then form a permanent mount.

OBSERVATION BY TRANSMITTED LIGHT

The fact that an opaque specimen had been rendered translucent, did more than solve the problem of photography. It permitted observation as well as photography of permanently mounted scolecodonts by transmitted light. The use of a biological microscope also became possible. Low power revealed the details of general morphology, including some obscure features, such as markings and attachments. The fine internal structure of scolecodonts, such as fibers and a crenulated band bordering the fossa, were visible under high power.

In the illustrated specimen (pl. 1, figs. 1–5), details of the fibrous construction of scolecodont denticles can be seen. The central part of each denticle has a triangularly arranged mass of fibers, bounded on each side by a series of small, arc-shaped fibers.

While this is merely a preliminary report of early results, the new method is being used by the senior author in a study of over 1,000 Leonardian scolecodonts. As several genera are involved in the Permian collection (Tasch and Stude, 1960) and include numerous species, it will be of interest to determine the differences and similarities in the fine structures within a species and within several species of the same genus.

FURTHER APPLICATIONS

This new simple technique may be of value in the study of various microfossils (pl. 1, fig. 6) that are especially darkened or have a high organic content. Experiments are under way to test whether or not it may be used on macrofossils also. For example, the Clorox treatment oxidized all the carbon in carbonized graptolites in a black shale. The configuration of the graptolites remained intact.

Experiments on very thin slices of highly organic shales and calcareous bioclastics show some clarification of contained microorganisms. The dark organic bands in some small algae of Pennsylvanian age, studied in thin sections of limestone, were partially oxidized by the Clorox treatment.

At any rate, other workers are urged to experiment with this method in the hope that new applications will be forthcoming. As presently developed, it should affect the study and classification of many scolecodont species that respond to the treatment.

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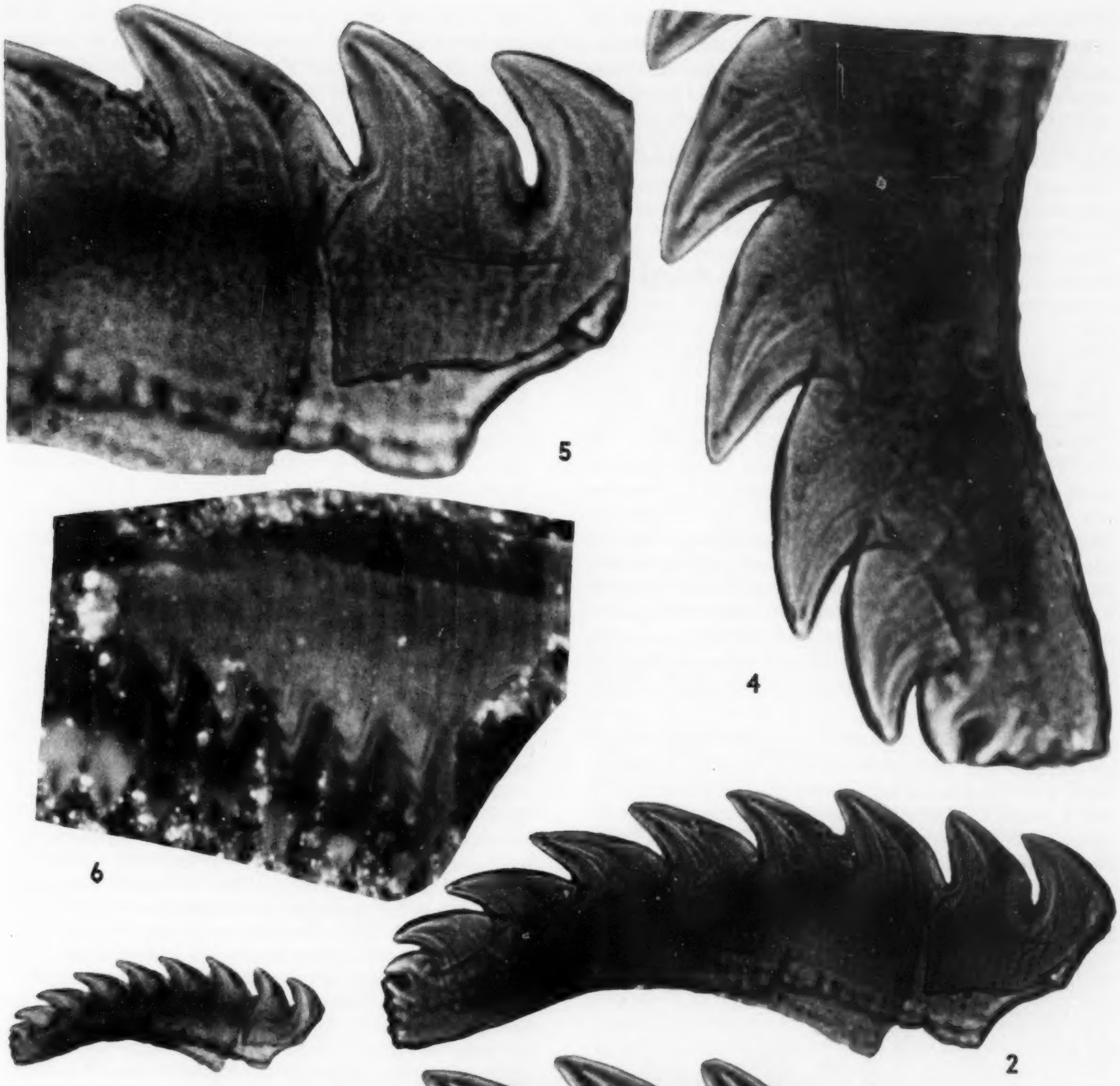
PLATE 1

1–5 *Arabellites falciformis* (?)
1, broken specimen, right jaw, transmitted light, × 125, Fort Riley limestone, Wolfcampian, Kansas. A completely opaque object appearing black in reflected light was found to become translucent when treated with Clorox. 2, same specimen, × 287.5. Note the fine detail beginning to appear. This includes a crenulated band as a margin around the fossa, and a peculiar incurvature at the base of the second visible denticle from the anterior end. 3, same specimen, × 387.5. Fine structures include a central band of fibers converging towards the apex of denticles and a continuation to the outer margin, in parallel rows, of individual fiber-strands of the central fiber-band. 4–5, same specimen, × 615. All fine structures noted above are now much clearer and the nature of the most posterior denticles are brought out. These last structures appear to be a series of narrow, tusklike, reversely curved denticles.

None of the fine structures observed in figures 1–5 have been seen or reported previously; these figures should be compared with illustrations or photographs of retouched specimens in the literature.

6 *Polygnathus sp.* Conodont on black shale slab; Hushpuckney shale member of Swope limestone, Kansas. Although the en echelon structure of these denticles has been seen before, the Clorox treatment brings out details not otherwise available than in thin sections. Successively higher magnification can also be used after this treatment for clarification of the finest structures observed, × 183.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ABSTRACT

The economic value of palynology is an accepted fact but its practice is misunderstood by some oil companies. As in other disciplines, palynology has its limitations. These stem from the unsuitability of the method in certain rocks, a lack of knowledge on the part of the palynologists often hired by managements, the inferior equipment in use, and the absence of literature available. Those companies who understand these problems are successfully resolving many pertinent questions. Suggestions are made that will advance the value of palynology to science and industry.

Palynology as a tool for economic geology

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The value of palynology to economic geology, particularly in the petroleum industry, is well established and has been widely publicized in numerous trade journals here and abroad. The fact that palynology will resolve many problems of stratigraphy and paleoecology need not be further expanded, except to emphasize that the method will increase in value as it becomes better understood.

This paper is an attempt to summarize some difficult problems in the application of palynology to industrial work, and to sound a word of caution to those who regard it as a panacea for all stratigraphic difficulties. Palynology has its limitations and, in justice to the science, these must be recognized.

The basis of palynological stratigraphy is evolution, paleoecology, and paleogeography. Most sedimentary rock sequences have characteristic palynological assemblages. Phyla and genera of palynological fossils are diagnostic for age determinations of the order of epochs or longer time intervals. For shorter time intervals most age determinations must be based upon assemblages and relative abundance of species. However, many assemblages are difficult to evaluate because it is almost impossible to separate factors of causal ecologic relationships and time relationships. For example, many Pleistocene palynological facies without accompanying geological information are problematic, and progressively older facies become more vague as the number of extinct forms increases. At present, the older strata must be correlated empirically. Because fossil assemblages represent only a fraction of one or more life communities, paleoecological criteria differ from those of neoecology. Ecological succession within Pleistocene time is relatively well understood, but little is known about it in earlier ages. It is reasonable to assume, however, that ecological succession functioned with equal importance throughout geological time, and, when better understood, will be a significant stratigraphic tool.

Imposed upon the problem of local facies is the factor of geography. It is extremely difficult at this moment to make close palynological correlations of recent assemblages in sediments collected at widely separated points, or in markedly different environments. By way of example, surface deposits from the everglades of Florida cannot be equated, on biota, to those of the tundra in Canada. This and similar problems can be resolved by short-distance correlations, and, when all facies are associated, they will be seen in the perspective of palynological geography. In the lower latitudes, the floras and faunas have been relatively stable over long periods of geological time. These biota extended into the higher latitudes during warm periods and retreated during cooler. The relatively stable nature of some tropical floras and faunas is one of the reasons for the difficulty in zoning many geological sections in the lower latitudes. Where time intervals were not long enough to have allowed evolutionary change, or where physical conditions did not differ sufficiently to cause biotic migration, zonation of sediments must be done with specific assemblages. Most modern tropical communities are local, and probably were likewise in the past. This condition limits close correlation to short distances. Palynological assemblages in tropical sediments are generally rich in number of species and poor in the number of individuals of each species. This same condition applies to extant tropical floras and faunas. Such fossil assemblages are difficult to correlate and require detailed study. Similar problems should be anticipated in the higher latitudes in sediments deposited during warm periods.

Palynology is valuable in equating continental and marine biofacies. Many brackish-water and marine sediments contain abundant fossils from the continent.

Fossil spores, pollen, and cuticles from the land can reveal the age and environment upon the continent and complement similar determinations made from microfossils of marine environments. Distance from ancient shorelines and the type of sediments studied will materially effect these correlations, and to resolve them requires considerable knowledge and experience.

Another perplexing problem is that of reworked sediments containing palynological fossils derived from older rocks. Some reworked deposits contain few or none of the palynological elements that were extant at the time of the reworking. The resolution of this problem requires collaboration of palynologist, sedimentary petrologist, and physical geologist.

A brief history of the science is desirable in order to point up some of the problems current in industrial palynological laboratories. Palynology began about 1916 as the study of spores and pollen, and was primarily concerned with the examination of Quaternary peats. About 1928, it was expanded to include the fossil spores and pollen of older sediments, particularly those in coals and shales. Recently, the field has been further expanded to include other fossil plant and animal micro-organisms that are generally smaller than the Ostracoda and Foraminifera. For many years, possibly since the time of Ehrenberg and until about fifteen years ago, palynology, as we know it today, was essentially an academic science, interesting but not economically important, and, therefore, to many people, essentially useless. In 1945 the petroleum industry discovered that palynology had potential as a stratigraphic tool. Because fossil plants had never contributed much to the resolution of marine and brackish-water stratigraphic problems, and, because oil geologists seldom had botanical training, there was great hesitancy on the part of most companies to utilize the method. In 1945, two major companies undertook small problems, and were successful in establishing stratigraphic correlations. The growth of palynology in the oil industry was slow the first five or six years, but then it mushroomed and millions of dollars have been spent establishing palynology laboratories all over the world. Almost every major company and many independents have such laboratories. In a few companies, palynology is receiving adverse criticism because it is not the nostrum that some have advertised it to be, and because uninformed technical and executive managements are expecting mature answers from a science still in its infancy.

This criticism should not be leveled at the science of palynology, for it probably has the greatest potentiality to the oil industry of all branches of paleontology, especially in the coming days of air-drilling. The fault, if there is a fault in the failures of its application to petroleum geology, is a human one. The inadequate training and inexperience of the people employed to do this highly technical work has contributed to disillusionment in some companies, and it will do so in others. Another part of this disillusionment can be laid to too great expectation and to too little understanding on the part of management. The establishment of a palynology laboratory does not result from the purchase of an inferior microscope, a fume-hood, a few chemicals, a smattering of literature, and a revamped employee from another part of the company. A functional palynology laboratory will cost less than a geochemical laboratory, and many times less than a geophysical installation. The purchase of good equipment will more than pay for itself in quality of work and in time. The palynologist should be the best available, and not someone who is transferred from another job because he appears to be the only person interested, or somebody who otherwise would be dropped because of a cut-back in personnel. One would not normally hire a geophysicist to do the work of a geochemist; likewise it is unrealistic to place palynological responsibility with untrained help. Palynology, in its ramifications, is as complicated as any field of economic geology. Also, it is a method requiring the employment of many special techniques which, when practiced, are time consuming. The hiring of one palynologist to process, examine, and complete projects without the aid of well-trained technicians will not produce a sufficient amount of information to satisfy management. It is safe to state that a palynologist with one well-trained technician will turn out three times as much work as one person working alone.

In the numerous publications describing the uses of palynology in the petroleum industry, little or no mention is made of the problems that are difficult, or that cannot be resolved by the method. These difficulties can be divided into two categories; first, those that are inherent in the science as we know it today, and second, those that come from management. The first has been discussed, and regardless of the complexity of those problems, many can be resolved by careful and unhurried research. At this time, much of palynology is not on the production line.

Those problems that are intrinsic to the laboratory and to the field collector are also many, but they too can be overcome with understanding and effort. Much of the collecting, for the palynologist in the laboratory, is done by field men with little appreciation of the habitats of these fossils. Often, the wrong rock type is sampled and the results are disappointing. Instances where thin shale partings between dolomites have been overlooked, or chunks of lignitized wood have been collected instead of the amorphous coal. Incompletely collected sections often miss the marker beds, and the use of improperly cleaned cores have done strange things to palynological interpretation. The palynologist must be a field man, along with his other talents, to be of the greatest service to his company, and he should be allowed to collect as many samples as is practical.

Contamination is a curse to palynology because it takes so little to be disastrous. The technician must have the conscience of a bacteriologist with his cultures. Preparation techniques are an integral part of the science. Some company palynologists have a tendency to process all samples the same way. This results in unsatisfactory

recoveries, or in inferior preparations. Samples vary widely, and careful attention to this fact is absolutely necessary. A practical balance must be maintained between the perfection of museum preparations and those of a hurried and sometimes careless technician. In some instances needless pains are taken to make preparations of beautiful specimens, a feature seldom necessary in a commercial laboratory, while in others the preparations are so carelessly made that it is impossible to determine the true fossil assemblages in the samples. Preparation techniques are constantly changing, and a continued examination of the current literature will keep the palynologist informed.

Inadequate equipment will lead to unsatisfactory results. The microscope must have sufficient optical resolution. It should have phase contrast equipment for some fossil identification. Photomicrography plays a major part in the operation of a laboratory, but numerous commercial installations are sadly lacking in this equipment.

One of the most difficult problems with which to cope in the palynological laboratory is keeping abreast of the deluge of literature appearing in journals. Maintaining contact with current literature more than pays for the time and money it costs. Often, a fossil identity or an age problem is quickly resolved by reference to a good library, and it may save years of personal investigation.

The establishment of a comparison collection of both recent and fossil material will aid in critical and important identifications. Many of these forms may be secured by exchange, and such practice should be encouraged.

A word may be said concerning the training of an economic palynologist. It should be clearly apparent that the science is not a minor discipline, and the person qualified to attack its problems must have the widest possible background in geology and biology. The geologist is equipped to understand time and space problems but normally has little knowledge of plant and animal morphology, phylogeny, and ecology. His identifications of species tend to follow a size-shape system and thus he cannot utilize natural relationships and their ecological significances. The biologist who attempts stratigraphic work in palynology is handicapped by a lack of detailed knowledge of earth history and stratigraphic analysis. Future palynologists should be trained in both fields, and in allied disciplines.

In conclusion I would like to emphasize that palynology can resolve many stratigraphic and paleoecological problems that are presently cluttering the files of every exploration company. Consideration of the following points will greatly enhance the value of palynology as a stratigraphic tool:

1) Greater understanding of the natural affinities of palynological fossils.

2) Critical use of the composition and relative abundance of the species in palynological assemblages.

3) Comparison of the palynological assemblages with associated megafossil assemblages.

4) Utilization of data from sedimentation studies for environmental and historical information.

5) Utilization of statistical techniques in the analysis of fossil biotas and associated sedimentary facies.

ABSTRACT

Humic acid drilling-mud "thinners" derived from oxidized coal have been found to contain from 600,000 to 4,000,000 pollen and spores per gram of coal. Various brands of quebracho thinners contain, in addition to the primary constituent, quebracho extract, varying amounts of oxidized coal as a filler. Hence, such quebracho thinners are also a source of coal-derived pollen and spores. Palynologists, working with cuttings from which the drilling mud cannot be completely eliminated, must reckon with the built-in flora of the mud thinners.

Pollen in drilling-mud "thinners," a source of palynological contamination

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Drilling operators, especially in the petroleum industry, have developed to a very high degree the technology of the so-called muds that are circulated under pressure in the drill hole to provide the flux for the drilling process and to help seal the walls of the hole. Different combinations of solids are suspended in the mud, and chemical treating agents are dissolved in it, to give it the required properties. These requirements for the mud vary with the rock being drilled, since the rock fragments produced by the drilling bit become a part of the mud. One problem with which mud technologists must cope is the tendency for clay particles to flocculate, making the mud too thick to circulate properly. To counteract this tendency, various "thinners" are used, which have in common the formation of bonds with clay particles, preventing flocculation and, hence, increasing fluidity. Among the common thinning agents are natural products that are weak organic acids, especially quebracho wood extract, rich in tannic acid, and oxidized low-rank coals, rich in humic acid. Mangrove bark is used to some extent in the same way as quebracho extract. The most commonly used oxidized coal is naturally oxidized North Dakota lignite, sometimes called "leonardite" or "slack." This substance, which occurs near the surface in western North Dakota in very large tonnages, is presumed to have been produced by mild oxidation *in situ* from normal North Dakota lignite (Tongue River formation, Paleocene). It has a relatively low calorific value, being naturally oxidized, and a very high moisture content. Hence, it is usually regarded as a nuisance by the lignite mining industry and is normally thrown away on the spoil banks. It is very high in humic acids, often being nearly 100 percent soluble in slightly alkaline water, and it has been used for various special applications, such as in the preparation of a brown dye (Traverse, 1954). Its principal application now is as a thinning agent in drilling muds, as discussed above. Exact figures are not obtainable from the North Dakota Department of Mine Inspection, but on the basis of statements of mining companies, the senior author estimates that about 40,000 tons of oxidized North Dakota lignite was mined in 1957 for use in drilling muds. Some oxidized coal for this purpose is also mined in New Mexico and elsewhere. This type of coal is processed and bagged for sale to drilling operators by a number of companies. The processing consists mostly of drying and pulverizing the coal. Since the substance is alkali-soluble, solid alkali is often added to the lignite to insure solubility in neutral drilling water. The finished product is sold under a variety of trade names, CARBONOX and TANCO being the two brands investigated in this study.

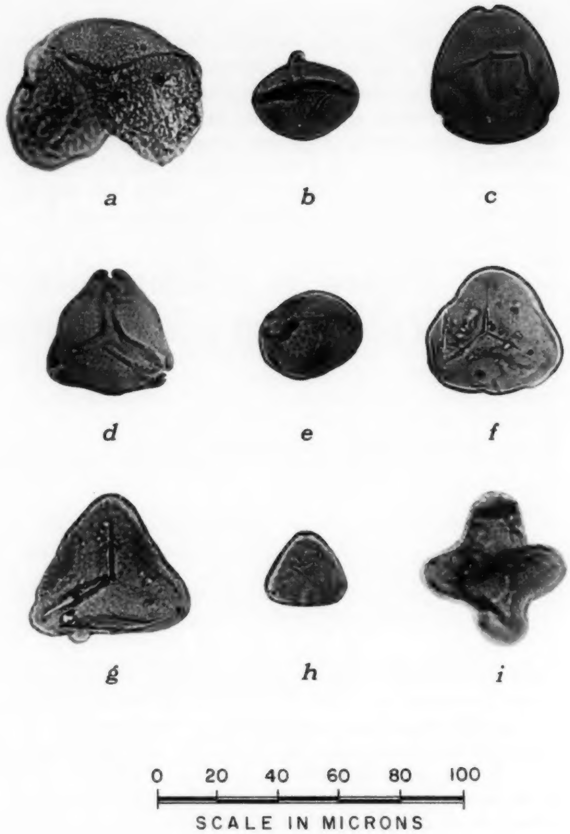
Since they are oxidized coals, these substances are exceptionally rich in pollen, a circumstance of potential importance to palynologists. As shown in Table 1, a sample of the raw material from which CARBONOX is made, obtained from the Baroid Division, National Lead Company, contained over 4,000,000 pollen and spores per gram! Additives made from New Mexico "lignite" (probably a sub-bituminous coal) are also rich in pollen, though less so than CARBONOX. The flora of the North Dakota lignite is a typical Tongue River formation (Fort Union group, Paleocene) complex (see text-figure 1, *a–d*). The source of the New Mexico oxidized coal studied is not definite, though it is in all probability

from the Mesaverde group (Upper Cretaceous) of the Gallup region. Typical representatives of the flora of a sample of drilling-mud additive from New Mexico coal are shown in text-figure 1, *e–h*.

Quebracho and mangrove products are used as thinners in the same way as oxidized lignite. Quebracho thinner is made from an extract of the tannin-rich wood of the quebracho tree of South America. This species is *Schinopsis lorentzii* (Griseb.) Engl., according to Hill (1937). Mangrove bark is dried, pulverized, and bagged for use as a thinner. As shown in Table 1, quebracho extract and mangrove bark are comparatively pollen-free. However, since bulk pulverized quebracho extract tends to cake, it is usually mixed with varying amounts of anticaking filler. In many instances this filler is oxidized lignite, so that commercial quebrachos are often rich in extraneous pollen. Quebracho 90–10 (Table 1, item 8), for example, contains nearly 200,000 pollen and spores per gram. The microflora is the same as that in Carbonox, Table 1, item 2, and it is clear that Baroid's Quebracho 90–10 is made by adding Carbonox to quebracho extract.

It is evident that if samples of well-cuttings have been contaminated with drilling muds containing oxidized coal, or quebracho that has been adulterated with such coal, a serious palynological problem can result. Such cuttings would have to be cleaned carefully to eliminate contamination; this is not always possible if the cuttings are fine. Cores or sidewall cores are easier to clean and are not likely to be contaminated with mud, except on the surface, unless the material is permeable. However, the junior authors of this paper, in the course of a drilling project in relatively unconsolidated Pleistocene material in the San Augustin Plains, New Mexico, have recently experienced serious mud contamination of the cores obtained. Cores drilled from a sandy zone at a depth of approximately 950 feet, with oxidized North Dakota lignite (Carbonox) in the mud, had to be redrilled with muds not containing lignite. The original cores were so badly infiltrated with polleniferous mud as to be useless for palynological analysis. The Paleocene pollen flora of the contaminating lignite includes types that may be confused in routine analysis with Pleistocene forms found in the cores.

The contamination problem is naturally more severe as the age of the investigated rock approaches that of the oxidized coal used in the mud. Pollen from oxidized North Dakota lignite is little coalified and hence has about the same appearance as to color and structure as pollen from modern sediments. Pollen from New Mexico coal is somewhat more coalified, and it appears darker in color and denser than pollen from modern sediments. It would seem important that palynologists should know the pollen flora of the drilling mud used in producing their samples, especially where cuttings that cannot be cleaned are being investigated. One should avoid using as marking species, forms that occur in the mud or that closely resemble mud-fossils. In some instances it will be possible to recognize the mud pollen by its color and



TEXT-FIGURE 1

Photomicrographs of pollen from drilling-mud "thinners." All magnifications × 500.

a) Vesiculate coniferous pollen grain from North Dakota oxidized lignite of Tongue River formation (Paleocene): raw Carbonox. Same sample as represented in Table 1, item 2.

b) Taxodiaceous pollen grain, probably *Sequoia*, same origin as *a*.

c) Triporate pollen grain, polar view, midfocus, same origin as *a*.

d) Triporate pollen grain with characteristic triradiate furrow, polar view, midfocus, same origin as *a*.

e) Monolete, verrucose spore, proximal view, from presumably Upper Cretaceous oxidized coal of New Mexico: Magnet Cove New Mexico "Lignite". Same sample as represented in Table 1, item 5.

f) Trilete spore, proximal view, same origin as *e*.

g) Trilete spore, proximal view, same origin as *e*.

h) Triporate pollen grain, polar view, same origin as *e*.

i) *Aquilapollenites* sp. from Magnet Cove Q–X Quebracho. Same sample as represented in Table 1, item 9. The existence of this and other Cretaceous pollen and spore forms in the quebracho probably indicates that a Cretaceous coal was mixed with the quebracho as a filler.

TABLE 1

POLLEN CONTENT OF VARIOUS MUD "THINNERS"*

Item	Product	Origin	Pollen and spores per gram (as received weight)
1	North Dakota "leonardite"	Oxidized lignite of Tongue River formation (Fort Union group: Paleocene), Knife River Mine, Gascoyne, Bowman Co., North Dakota.	580,000
2	Raw Carbonox, Baroid Division, National Lead Co.	As above, but from National Lead Company Mine, near Haynes, Adams Co., North Dakota.	4,362,000
3	Hydrocarb, Baroid Division, National Lead Co.	Same as above item but with solubilizing alkali added.	2,000,000
4	Tanco, Milwhite Mud Sales Co.	Oxidized coal, presumably North Dakota lignite, as above two items.	814,000
5	Magnet Cove New Mexico "Lignite," Magnet Cove Barium Corp.	Oxidized, probably subbituminous coal of Mesaverde age (Upper Cretaceous).	684,000
6	Pure quebracho extract from Magnet Cove Barium Corp.	Presumably extracted from quebracho wood in South America.	200
7	Man-Tan, Bariod Div., Nat. Lead Co.	Mangrove bark (presumably *Rhizophora mangle* L.), processed and crushed fine.	500
8	Quebracho 90-10, Baroid Division, National Lead Co.	Quebracho extract mixed with oxidized coal, presumably raw Carbonox North Dakota lignite (see above).	167,000
9	Magnet Cove Q-X Quebracho, Magnet Cove Barium Corp.	Quebracho extract mixed with an unidentified oxidized coal of Cretaceous age.	12,000
10	Mil-Quebracho, Milwhite Mud Sales Co.	Quebracho extract, mixed with oxidized coal, presumably North Dakota lignite.	1,600
11	Q-Broxin, Baroid Division, National Lead Co.	Ferrochrome lignosulfonate, manufactured by Puget Sound Pulp and Timber Co.	0

* Four samples of barites and eleven samples of bentonite clays were analyzed. These major constituents of drilling muds were found to be barren, or practically barren, of pollen.

texture, in contrast to the pollen that belongs in the samples. In routine analyses such separation is likely to be tricky, however. In some situations where cuttings are used for palynological work, palynologists may be in the position of having to recommend that nonpolleniferous thinners be used.

ACKNOWLEDGMENTS

The senior author would like to express thanks to W. K. Godfrey, Shell Development Company, and R. J. White, Baroid Division, National Lead Company, who helped him by securing samples of the products studied in this investigation and by explaining some of the technical aspects of drilling-mud technology that were involved in the study.

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AUSTRIA

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The importance of the Fusulinidae for stratigraphic correlation over great distances is the subject of a paper by F. Kahler (1960, Geol. Rundschau, vol. 49, pp. 92–97). The fusulinid horizons must always be correlated with the stratigraphic results obtained on the basis of other faunal and floral groups. Notwithstanding all our success in recognizing genuine stratigraphic identities, considerable difficulties are still being encountered in the field of paleogeography.

In a special volume of its "Jahrbuch" (Sonderband 5, 1960), the Geological Survey of Austria published four contributions to the microstratigraphy of the Triassic of the eastern Alps. R. Oberhauser described foraminifera and microfossils *incertae sedis* of the Ladinian and Karnian stages of the Triassic from the Eastern Alps and from Persia (pp. 5–46, 6 pls.); Edith Kristan-Tollmann, Rotaliidea from the Triassic of the Eastern Alps (pp. 47–78, 15 pls.); K. Kollmann, Ostracoda from the Alpine Triassic (pp. 79–105, 6 pls.), and W. Klaus, Spores of the Karnian stage of the eastern Alpine Triassic (pp. 107–183, 11 pls.). It is not surprising that in these detailed studies the authors described a large number of new genera and species, because until recently, only very little was known about the microfauna of the Triassic. Establishing the various forms as accurately as possible goes hand in hand with characterizing individual horizons. The paper by Klaus is a monographic representation of the spore content of the Karnian, which supports his establishment of a subdivision of the Triassic by means of spores.

Our knowledge of the Alpine Upper Cretaceous ("Gosau") was enlarged by a major paper by A. Tollmann (1960, Geol. Bundesanst., Jahrb., vol. 103, pp. 133–203, 16 pls.) describing a rich foraminiferal fauna from the hitherto little-known Alpine upper Coniacian, collected in the Gosau Basin of Weissenbach, near Aussee in Styria.

In connection with intensive research on the Flysch sediments and related problems recently carried out in Austria, a team of Vienna geologists had an opportunity, in 1959, of studying some interesting sections in the area of Trieste, Italy. Contrary to the conditions prevailing in Austria, the tectonics are less complicated there, and, above all, the basement on which the Flysch sediments were laid down is well exposed. K. Gohrbandt, K. Kollmann, H. Küpper, A. Papp, S. Prey, H. Wieseneder, and Gerda Woletz published their observations and conclusions in the "Verhandlungen der Geologischen Bundesanstalt," (1960, vol. 2, pp. 162–197, 3 pls., 3 text-figs.). The calcareous Upper Cretaceous is followed by a calcareous Eocene series with freshwater limestones (the Promina beds) in the lower part and fully marine limestones with Miliolidae, *Nummulites*, and *Alveolina* in the upper part. These are followed by the marls and sandstones of the Flysch proper. The change of facies from the organic limestones to the clastic Flysch sedimentation is thought to be linked somehow with relief-forming processes in the hinterland. According to the *Assilina* species determined, the youngest parts of the marine limestones, i.e., the *Alveolina* limestones, belong to the older Lutetian. The marls and shales of the Trieste Flysch contain calcareous faunas with abundant *Globigerina* and *Globorotalia;* in this respect they differ basically from the microfaunas of the Northern Alpine Flysch, which contains mostly arenaceous forms, often interpreted in the literature as cold-water faunas. As to its age, the sections of the Trieste Flysch investigated are considered to be lower middle Eocene. The planktonic faunas give probable bathymetric indications for depth ranges between 700 and 1200 meters. The ostracode fauna in the border zone between the limestone and Flysch facies seems to indicate a water depth of several hundred meters.

The micropaleontological literature on the Neogene of Austria was enriched by a monograph by K. Kollmann on the Cytherideinae and Schulerideinae (new subfamily of Ostracoda) (1960, Geol. Ges. Wien, Mitt., vol. 51, pp. 89–195, 21 pls., 5 text-figs., 5 maps, and tables). After the publication of the classic work by A. E. Reuss on the fossil Entomostraca of the Austrian Tertiary (1850), many years passed during which little attention was paid to the ostracodes. It was only during the most recent period of Tertiary research, in connection with oil exploration, that renewed interest was directed toward this group of microfossils; this interest was caused partly by the fact that, in microfaunal respects, some stages, e.g., the Pannonian of the Vienna Basin, can be subdivided only on the basis of the ostracodes. Kollmann's excellent paper is the first monograph on a part of this large field. From the material investigated thus far, the author selected the Cytherideinae and the Schulerideinae on account of their abundant individuals and their stratigraphic usefulness. The general part of the publication contains an accurate description of the 96 localities from which the material was collected. The succeeding stratigraphic part contains three tables, which extend far beyond the borders of Austria. Chapters in the paleontological section provide the stratigrapher with a good introduction to the problems of ostracode taxonomy. In grouping the shell characters of the Cytherideinae, the author introduces "Tribus" terms. Of the two subfamilies, there were described, in all, seven genera and twenty-nine species

and subspecies, of which one genus and twelve species and subspecies are new. A key, worked out in the form of a table, relates to the Tertiary and Recent genera of the Cytherideinae and Schulerideinae with their typical representatives in the area involved. The paper is enhanced by the carefully selected, extensive illustrations.

A. Papp reported on the occurrence of *Miogypsina* in central Europe and its significance in Tertiary stratigraphy (1960, Geol. Ges. Wien, Mitt., vol. 51, pp. 219–228, 4 illustrations). *Miogypsina gunteri* Cole was described from southern Slovakia and *Miogypsina intermedia* Drooger from the upper Austrian Molasse zone, thus establishing the middle Aquitanian and upper Burdigalian in those localities. The stratigraphy of the zones from which these *Miogypsina* species were collected was discussed; it had previously been based on mollusks and foraminiferal faunas. The age-determinations of the rocks studied were partly confirmed and partly emended on the basis of the evolutionary lineage of *Miogypsina*.

An occurrence of *Miogypsina* in British West Africa (Cameroon) was reported by Inge Küpper in the completion of a paper commenced by her late husband, Klaus Küpper, (1960, Sci. Repts., Tohoku Univ., ser. 2, Spec. vol. no. 4, pp. 56–69, 3 pls., 3 text-figs.). The material studied comes from surface outcrops of older Burdigalian age. Of the five species described, one is new.

A paper by J. Kapounek, A. Papp, and K. Turnovsky dealt with problems involved in the subdivision of the Tertiary in Lower Austria north of the Danube (Outer and Inner Alpine Vienna Basin, Waschbergzone) (Geol. Bundesanstalt, Verh., 1960, pp. 217–227). In particular, the beds of the older Oligocene, Aquitanian, Burdigalian, and Helvetian were characterized micropaleontologically and their distribution outlined. With respect to nomenclature, the term "series" was introduced because the paleontologically well-founded subdivisions of the Neogene in the Vienna Basin cannot be correlated satisfactorily at present with the international stages of the Miocene.

Three publications were devoted to investigations of fossil Discoasteridae. In continuation of an earlier publication, H. Stradner reported on the fossil Discoasteridae of Austria (1959, Erdöl-Zeitschr., pp. 472–488, 5 pls., 2 text-figs.). Together with E. Martini, Stradner presented some data on *Nannotetraster*, a stratigraphically significant new discoasterid genus (1960, Erdöl-Zeitschr., pp. 266–279, 3 text-figs.), the first representatives of which were previously known from the Upper Cretaceous. Finally P. Brönnimann and H. Stradner published an interesting study on the foraminiferal and discoasterid horizons of Cuba and their intercontinental correlation (1960, Erdöl-Zeitschr. pp. 364–369, 1 pl., 2 text-figs., 1 table). The table clearly indicates the correlation of the Tertiary discoasterid horizons of the Havana area with the stratigraphy established by means of pelagic and larger benthonic foraminifera. For the time being, correlation by means of Discoasteridae, comparable with that provided by planktonic foraminifera, is still impossible, but it will be attempted in the near future. At present, correlations by means of discoasterids are valuable chiefly in cases where usable planktonic foraminifera are not available. Various discoasterid associations in the Paleogene of Cuba can well be compared with those of other countries and continents; this indicates the possibility of approaching intercontinental correlation. Since 1960, Dr. Stradner has been working with the Geological Survey of Austria.

A fundamental paper on the systematics of the calcareous flagellates was published by E. Kamptner (1958, Archiv Protistenkunde, vol. 103, pp. 54–116). Besides his previously mentioned paper on the Triassic spores, W. Klaus published a pollen-analytical study of peat from Lower Austria. The section covers the late glacial and the complete postglacial period up to the present (1960, Austria, Geol. Bundesanst., Verh., pp. 72–77, 1 table). A contribution to the techniques of micropaleontology is offered in a note by Inge Küpper on the preservation of foraminifera by means of nitrovarnish (1960, Austria, Geol. Bundesanst., Verh., p. 252).

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In part due to the demand for geologists by the only Brazilian Oil Company, Petróleo Brasileiro S. A. – PETROBRÁS, five new geological schools have been set up since 1958 by the Universities of Recife, Rio de Janeiro, São Paulo, Ouro Preto, and Porto Alegre. All these schools have classes in micropaleontology, and some of the first graduates have already been hired for the laboratories of Petrobrás. In the Geological School established by Petrobrás in 1957 in Salvador, Bahia, an advanced course on micropaleontology will start in 1961.

DIVISÃO DE GEOLOGIA E MINERALOGIA, RIO DE JANEIRO

In the laboratory of the Brazilian Geological Survey, Professor F. W. Sommer and his assistants are engaged especially in the study of pollen and spores. General micropaleontological material is being processed by the students of the Rio de Janeiro Geological School, who use the facilities of this laboratory during the course.

INSTITUTO DE CIÊNCIAS NATURAIS, UNIVERSIDADE RIO GRANDE DO SUL

Under the direction of Professor Irajá Damiani Pinto, the paleontological department is carrying on the study of ostracodes and foraminifera, and recently also started a special research program on pollen and spores. Irajá Damiani Pinto and Y. T. Sanguinetti are completing a paper on ostracodes, dealing especially with a revision of the genera *Metacypris*, *Cytheridella*, *Bisulcocypris*, and others. It is of special systematic and stratigraphic interest in connection with nonmarine Mesozoic sediments. Cenozoic marine and freshwater ostracodes are being studied by Y. T. Sanguinetti, L. de Ornellas, and S. Kotzian.

Darcy Closs, M. Barberena, and M. Madeira are studying Tertiary and Recent foraminifera. Two papers on Recent forms from the Brazilian coast, Bahia and Rio Grande do Sul, were published in 1960. A. Zíngano and A. Cauduro are engaged in palynological research on Pennsylvanian material from Rio Grande do Sul.

UNIVERSIDADE DE SÃO PAULO

In the Department of Geology and Paleontology, Dr. Setembrino Petri is finishing his study of Cretaceous foraminifera from Sergipe, northeastern Brazil. Surface samples and well cores have yielded foraminifera from various Cretaceous formations. Several distinct zones were recognized on the basis of the faunas, which permit tentative correlations with those of North America, Colombia, and Venezuela. Dr. Petri's paper should be ready for publication in the near future.

PETRÓLEO BRASILEIRO S. A. (PETROBRÁS)

Three laboratories of Petrobrás are now engaged in micropaleontological research. At Belém, the laboratory, under the direction of Octavio B. Mello, assisted by Eglemar C. Lima and some trainees, is carrying out routine examinations of all surface samples submitted by geological parties and of cores and ditch samples from fourteen exploratory rigs drilling in the Amazonas and Maranhão basins. Silurian and Lower and Middle Devonian spores, scolecodonts, hystrichospherids, and Chitinoza have been studied for many years, and well established forms permit very good identification of the beds and correlation over wide distances. Foraminifera, conodonts, and other microfossils are very helpful in the age determination and correlation of Pennsylvanian formations. The laboratory at Ponta Grossa, under Hélio de Sá Brito and several trainees, is continuing the routine examination of surface and subsurface samples from the Paraná sedimentary basin. Devonian Chitinozoa, scolecodonts, hystrichospherids, and spores, and Pennsylvanian and Permian spores and a few other microfossils are used continually for age determinations and correlation of formations. Your correspondent, for nearly two years now assigned to the Rio de Janeiro headquarters office of the Exploration Department of Petrobrás, frequently visits all these laboratories and occasionally has an opportunity to carry out some special micropaleontological research.

The only commercial oil production in Brazil is still restricted to the Recôncavo of Bahia, and several significant new discoveries have resulted from the concentrated exploratory efforts carried on in that State. In order to obtain data for the solution of the many stratigraphic problems and for the age determination and correlation of samples, PETROBRÁS in 1957 set up a well organized micropaleontological laboratory in Salvador, Bahia. This laboratory is presently staffed by three senior paleontologists, Helmut Müller, John C. Troelsen, and Rolf T. Weber, several assistants and trainees, and an adequate number of helpers. Several thousand samples are processed annually, and pollen, ostracodes, and hystrichospherids have proved very helpful for establishing well-defined zones for the stratigraphic subdivision of the brackish to fresh-water Jurassic to Cretaceous formations of the Recôncavo basin. Microfossils have been used extensively for correlation with the neighboring Tucano basin, as well as with the separate Sergipe-Alagoas basin. In view of the lithologic similarity of some of the formations, microfossils are widely used for age determinations of samples; for this purpose, some of the surface geology crews are being especially equipped with jeep-mounted auger drills to obtain subsurface samples for micropaleontological analysis in regions of deep weathering.

The Salvador laboratory is also studying foraminifera and marine ostracodes from Cretaceous and Tertiary formations of the coastal sedimentary basins of Alagoas, Sergipe, and Espírito Santo. Microfossils have proved to be especially useful in helping to solve complex stratigraphic problems and in establishing the age of some of the formations known only from subsurface samples in the Sergipe-Alagoas basin. Karl Krömmelbein, who worked in the Salvador laboratory until March, 1960, will publish some systematic papers on Brazilian Cretaceous ostracodes in the near future.

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GERMANY

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In 1960, stratigraphy in Germany was even more in the foreground of micropaleontological work than in previous years. During 1960 there have been published about 90 references, of which 30 are on microfossils from the Tertiary, and 10 each on the Quaternary, Cretaceous, Jurassic, and Devonian. The remainder are divided between the Paleozoic and techniques. Most of the papers are on animal microfossils (foraminifera, ostracodes, conodonts). The 29 palynological works deal primarily with stratigraphic problems of the Tertiary. Four publications on other microfossils are devoted to nannofossils. The latter, dealing with the coccolithophorids, braarudosphaerids, discoasterids, and related forms, are by Erlend Martini, of the Geological-Paleontological Institute of the University of Frankfurt/Main. Besides the stratigraphic ages, Martini was able to obtain important taxonomic results. It is expected that in future this work will acquire more stratigraphic and paleogeographic importance.

Some of the palynological papers are outstanding for their taxonomic importance. The third part of the concise synopsis by R. Potonié, comprising all forms and groups of the "Sporae Dispersae," is available, together with supplementary notes and a general register, as a supplement to volume 39 of the Geologisches Jahrbuch, Hannover. Mr. and Mrs. Remy report the discovery of fertile and sterile branches of *Eleutherophyllum* which permitted maceration of spores. Similarly fortunate plant discoveries from the Carboniferous are described by N. W. Radforth and J. Walton. Their work contains illustrations of ten sporomorphs. New microbotanical discoveries are also reported from the Tertiary by W. Krutzsch, D. H. Mai and W. H. Zagwijn. Less fre-

quently described botanical groups have also been considered. For example, F. Stockmann and Y. Williere have described fourteen species of hystrichospherids from the Belgian Upper Devonian. E. Flügel described Rhodophyceae from the Rhaetian of the Steiermark, and F. Hustedt has investigated diatoms from the affluents of the lower course of the Weser, north of Bremen.

Among the publications on foraminifera, the following are taxonomically important: G. F. Lutze, in a study of sections in the region of the type locality of the Heersumer beds, identified a number of foraminifera from the Callovian and Oxfordian of northwestern Germany. Mr. and Mrs. Seibold identified foraminifera from the Oxfordian of southern Germany; their sponge facies, which completely deviates from the normal banked facies, enhanced the discussion of the relationship of the ecology of these foraminifera to the lithology. At the 21st International Geological Congress in Copenhagen, H. Hiltermann and W. Koch presented a paper on vertical ranges of 67 species in northern Germany. Various groups, i.e., *Neoflabellina*, *Bolivinoides*, *Stensiöina*, and *Gavellinella* are significant in biostratigraphy outside of northern Europe as well.

Contrary to the statement of J. Hofker, that the foraminifera demonstrate the equivalence of the type Danian with the type Maestrichtian, it was shown by E. Voigt that this is not true of the mollusks and Bryozoa. Some important papers have appeared on Tertiary foraminifera. Dorothea Spiegler has reported the first discovery of *Nummulites* in the Paleocene of northern Europe, J. H. Ziegler presented a morphologic analysis of assilines from well sections in the classic Eocene locality of the Kressenberg in Upper Bavaria. W. A. Berggren has made the first analysis of the stratigraphically important pelagic foraminifera of the lower Eocene (Ypresian), and C. W. Drooger and D. Batjes those of the Oligo-Miocene. Unexpected discoveries by Drooger of *Miogypsina* and *Lepidocyclina* in the upper Oligocene of the classic localities of Astrup and Doberg showed that the type Chattian is older than the Aquitanian of Bordeaux. Clara Ellermann has made an impressive comparative morphologic analysis of ten consecutive populations of *Elphidium subnodosum* from a pit section in the Niederrhein.

Among the investigations of ostracodes, the descriptions of Devonian forms by H. Blumenstengel and by H. Jordan are noteworthy. The former described 34 species, including *Entoprimitia rabieni* n. sp., from the Upper Devonian of Thuringia. Jordan presents 43 species, including several new ones, from the Lower Devonian of the Harz Mountains. E. Triebel, of the Senckenberg Museum, has made detailed morphological studies of the Macrocypridinae and the genera *Isocypris* and *Dolerocypris*, based on abundant material; he has provided excellent illustrations of the very fine details of the hinge, the muscle scars, the shell structure, and partly of the extremities. The taxonomy of Recent ostracodes has been studied by G. Hartmann, who described 32 species from the sandy, pebbly, and rocky Pacific coast of El Salvador.

Progress has also been made in research on conodonts. W. Ziegler has described 17 forms, including four new species, which are important in the stratigraphy of the Lower Devonian of the Rheinische Schiefergebirge. In the same volume (34) of the Palaeontologische Zeitschrift, W. Gross presented some new concepts in the study of conodonts based on his investigations of the morphology and histology of *Palmalepis* and *Polygnathus*.

The 84th Austauschsitzung für Mikropaläontologie und Stratigraphie (meeting for the exchange of micropaleontological and stratigraphic results) took place on November 25, 1960, in Hannover. K. Krömmelbein spoke on the stratigraphy and micropaleontology of the "Wealden" in northeastern Brazil. At the monthly meeting of the Deutsche Geologische Gesellschaft on January 28 in Wiesbaden, H. D. Pflug spoke on problems of palynology and stratigraphy in the younger Tertiary.

At the 7th annual meeting of the Geologische Gesellschaft of the D. D. R., held in Berlin from May 31 to June 2, micropaleontological themes were also listed in the program. W. Krutzsch and D. Lotsch discussed the stratigraphy and paleogeography of the Tertiary of Brandenburg. These reports were supplemented by Dorothea Spiegler, who discussed the microfaunal subdivision of the upper Eocene and Oligocene. In addition, N. Stoermer spoke on the microfauna of the Rhinow structure in Westbrandenburg.

At the 27th meeting of a group of Northwest German geologists, held June 8–11, 1960, in Norderney Udelgard, Grohne spoke on mud swamps in the coastal area, their development and destruction, and A. van der Werff on associations of diatoms in the Dollart region.

At the annual meeting of the Palaeontologische Gesellschaft in Munich, August 29-September 3, the following micropaleontologic subjects were covered among the 31 papers read: H. Schaub, "Development of nummulites and stratigraphy of the Lower Tertiary"; J. Hofker, "Age of the Maastricht tuffchalk and the Kunrader chalk, in relation to the Danian of Denmark, according to foraminifera"; E. Malzahn, "New Malacostraca (Phyllocarida) from the Niederrheinische Zechstein"; J. Hofker, "Foraminifera from the Hemmoor and Basbeck outcrops"; F. Bettenstaedt, "Speciation in the foraminifera"; J. Ziegler, "The direction of coiling in foraminifera and its taxonomic significance"; H. Hagn, "Statistical study of the species and subspecies of *Bulimina* in the Eocene of the Bavarian Helveticum"; and A. Seilacher, "New discoveries of ophiuran remains in the Paleozoic and their interpretation." Of great interest was the section on "Applied Paleontology" of the exhibit in the "Bayerische Geologische Landesamt," in which foraminifera were represented, among others, in the form of types, pictures, and vertical range tables.

During the subsequent field trip, C. H. Hagn showed the participants a number of micropaleontologically important type localities, among them those of J. G. Egger, C. W. Gümbel, and O. M. Reis. Opportunities were afforded to collect material from outcrops of the Häringer beds south of Kufstein (upper and lower Oligocene), from the Roll graben east of Neukirchen at Teisendorf (Eocene), the Rohrdorfer quarry "Sinning" at Neubeuern (Eocene, Stockletten), the Adelsholzener beds in the Teufelsgraben near Siegsdorf (middle Eocene,) the Gerhardtsreiter graben southeast of Siegsdorf (upper part of the Maestrichtian), and the Pattenauer beds of the "Wehrprofil" in Siegsdorf (uppermost Campanian—lowermost Maestrichtian).

At the 112th general meeting of the Deutsche Geologische Gesellschaft, September 21–29 in Bad Tölz/Oberbayern, H. Hagn spoke on the micropaleontology of the Helveticum section in Marienstein near Tölz.

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UNITED STATES — ROCKY MOUNTAIN REGION

DANIEL J. JONES

During the past twelve months, activity among micropaleontologists in the Rocky Mountain region has continued at a brisk pace, both in the institutions of higher learning and in industrial offices and laboratories. Most of the work consisted of studies on pollen and spores, late Paleozoic foraminifera and conodonts, Cretaceous foraminifera, and modern foraminifera and ostracodes.

Publications dealing with microfossils in the Rocky Mountain region were not nearly as numerous as during the previous year, but they continue to reflect the diversity of activity in micropaleontology in the area. Space will not permit more than a listing of some of the papers, selected to show the varied nature of the publications. These include: Schell, W. W., and Clark, D. L., "Lower Triassic foraminifera from Nevada" (Micropaleontology, vol. 6, no. 3, pp. 291–296, 1960); Peck, R. E., "Stratigraphic distribution of Charophyta and non-marine ostracodes" (Guidebook Intermountain Assoc. Petrol. Geol., pp. 115–121, 1959); Anderson, R. Y., "Cretaceous-Tertiary palynology, east side of the San Juan basin" (New Mexico Bur. Mines, Mem. 6, 1960); and Sadlick, W. "Fusuline correlations, Oquirrh formation and Durst group, eastern and central Utah" (Guidebook Intermountain Assoc. Petrol. Geol., pp. 82–89, 1959).

UNIVERSITY OF ARIZONA

Dr. Halsey Miller reports that the Department of Geology and the Geochronology Laboratories are now offering a wide variety of course work and research opportunities within the field of micropaleontology. Terah L. Smiley, Director of the Geochronology Laboratories, has continued his efforts to strengthen the palynological program offered by the University of Arizona. In addition to Dr. Lucy Cranwell-Smith, Dr. Jane Gray, and Dr. Paul Martin, Dr. Gerhart O. W. Kremp has recently joined the palynological staff of the Laboratories. Dr. Kremp will offer courses for graduate students in paleobotany and stratigraphic palynology. It is hoped especially to train students for stratigraphic palynological work in oil company laboratories. Dr. Kremp hopes also to continue as a WAE staff member of the U.S. Geological Survey, to continue his palynological work on the Pennsylvanian-Permian as well as on Cretaceous-Tertiary boundary problems. His new job will not interfere with his duties as editor of the Catalog of Fossil Spores and Pollen.

Dr. Jane Gray is continuing her late Tertiary pollen work in the Pacific Northwest of the United States and Canada, which began with the micropaleobotanical study of sediments associated with the middle to upper Miocene Mascall, Blue Mountains, and Stinking Water floras of east-central Oregon. She is studying pollen and plant microfossils from about 25 localities, ranging in age from middle Oligocene to upper Pliocene, in Washington, Oregon, Idaho, Montana, and southern British Columbia. In January, 1961, Dr. K. Sohma, Tertiary palynologist from the Institute of Biology, Tohoku Imperial University, Japan, will join her in this project. The present work is supported by a grant from the National Science Foundation. Dr. Gray has recently published several papers on Cretaceous and Tertiary micropaleobotany and has finished a report on an early Pleistocene pollen record from southeastern Arizona. Nearing completion is a manuscript on a Cenozoic microflora from Arizona and one dealing with a pollen study of a 3500-foot core from the Miocene Monterey formation, southern California.

Dr. Paul S. Martin is continuing his studies on late Pleistocene and postglacial sediments in southern Arizona and northern Mexico. His work is directed toward an understanding of vegetation and climate in the Southwest during the past 10,000 years. This work is being correlated with studies in archaeology, geology, and ecology. It is supported primarily by the National Science Foundation.

UNIVERSITY OF COLORADO

John Chronic is continuing to study foraminiferal distribution in Pacific atoll sediments. He has also been working on fusulinids from the Pennsylvanian of the Sangre de Cristo Mountains in southern Colorado, and in conjunction with John Hoyt, who completed his Ph. D. thesis here last year, he has been working on a paper entitled "Atokan fusulinids from the Casper formation, east flank of the Laramie Mountains, Wyoming." Hoyt is now with the Marine Institute of the University of Georgia. Dr. Donald Eicher has recently been collecting foraminifera from the Benton shale in this area. Last summer his paper on "Stratigraphy and micropaleontology of the Thermopolis shale" was published by Yale University. This was his doctoral dissertation at Yale.

The following theses, in which micropaleontology is used to a considerable degree, are in progress here: John Sharp is using foraminifera successfully for detailed correlation in the lower Mancos shale in western Colorado; Carl Newman is well along in a study of spores and pollen from three sections of the Mesaverde formation in northwestern Colorado; and Paul Merifield has begun a thesis on the Buck tongue and the Castlegate sandstone for which he plans to study the foraminifera and use them for correlation in northwestern Colorado and adjacent Utah.

COLORADO SCHOOL OF MINES

Professor J. Harlan Johnson has returned after several months in the hospital and is gradually resuming his full program of research on lime-secreting algae. During the past year, he has published two papers, one on Paleozoic red algae and the other on a new Cretaceous algae from Guatemala. He has three papers in press currently, including a major work on fossil algae from three atolls in the Pacific, which will appear as U.S. Geological Survey Prof. Paper 260-A. In addition, he has completed three new manuscripts and has three more in preparation.

Professor W. D. Mateer is continuing to offer courses in introductory and advanced micropaleontology, including one in paleoecology. His work on the modern microfaunas of the shelf area off Point Barrow, Alaska, will be augmented by a statistical analysis of the foraminifera by Dr. John Chronic of the University of Colorado; Dr. Daniel J. Jones, University of Utah, will investigate the ostracodes of the bottom samples.

Harry C. Kent, of the faculty of the Department of Geology, is currently working on a Ph. D. thesis at the Uni-

versity of Colorado which involves the micropaleontology of the lower Mancos shale in northwestern Colorado. The study is both stratigraphic and paleoecologic in nature.

UNIVERSITY OF NEW MEXICO

Roger Y. Anderson has completed his report on "Cretaceous-Tertiary palynology, eastern side of San Juan basin," and it has just been published as Memoir 6 of the New Mexico Bureau of Mines. He is, together with Douglas Kirkland, continuing his long-term studies on varves as an adjunct to climatic interpretation, together with isotopes and plant microfossils. In conjunction with these studies, he has developed a microtome technique for sectioning varves for pollen analysis. The season of deposition of varve components can be estimated by use of this technique.

John Emerson is conducting a detailed study of the environment of deposition of the Cretaceous Greenhorn limestone, which is apparently a *Globigerina* ooze formed under special conditions. Miss Janis Calmes is studying the palynology of the Cretaceous Bisti sandbar of the Bisti Field in the San Juan Basin.

NEW MEXICO INSTITUTE OF MINING AND TECHNOLOGY

Christina Lochman Balk reports that, although there is no micropaleontological activity in their Department of Geology, several interesting research projects are under way for the New Mexico Bureau of Mines and Mineral Resources, as reported by Dr. Kottlowski. Jan F. Van Sant, at the University of Kansas, is completing descriptions of fusulinids from the Whiskey Canyon Pennsylvanian strata of the Mud Springs Mountains and has differentiated 28 species from Desmoinesian, Missourian, and Virgilian equivalents. Wendall J. Stewart, of Texaco, Inc., Midland, Texas, is making phylogenetic studies of fusulinids, including new genera and species as well as their ranges, from the major exposures of Pennsylvanian rocks in New Mexico and Arizona. Don A. Zimmerman, Sun Oil Co., Richardson, Texas, is completing an evolutionary study of Atokan (Derryan) and lower Desmoinesian fusulinids (with special emphasis on *Wedekindellina* ancestry) from the Big Hatchet Peak quadrangle, Hidalgo County, New Mexico.

Samuel P. Ellison, Jr., at the University of Texas, aided by a grant from the Humble Oil and Refining Co., is studying the stratigraphic distribution of conodonts in Texas, New Mexico, and Arizona. Samples from the Sacramento Mountains of south-central New Mexico are included in the study. Garner L. Wilde and John W. Skinner, Humble Oil and Refining Co., Midland, Tex., are studying the fusulinid faunas and Pennsylvanian-Permian stratigraphy of the Big Hatchet Mountains in Hidalgo County. Walter L. Moore, Gulf Oil Corp., Roswell, is revising his thesis study on Upper Pennsylvanian fusulinids from the Mockingbird Gap section, northern San Andres Mountains, Socorro County. Augustus K. Armstrong, University of Cincinnati, has completed his Ph. D. thesis on the paleontology and stratigraphy of the Mississippian of southwestern New Mexico and southeastern Arizona, which included systematic descriptions of brachiopods, corals, blastoids, and endothyrids from the Escabrosa and Paradise formations. The thesis will be published by the Bureau. He has recently joined the staff of Portland State College, Oregon.

UNIVERSITY OF UTAH

Dr. Daniel J. Jones spent most of the summer travelling through England, Wales, France, Sweden, Norway, and Denmark. In London, he visited for several days with Dr. Tom Barnard and Dr. Eric Robinson of the University of London. He is continuing his work on ostracodes, and presented a paper on "Ostracodes of the Central Arctic Basin" at the annual Geol. Soc. America meetings at Denver in November, 1960. The recently published McGraw-Hill Encyclopedia of Science and Technology contains five articles by Dr. Jones, including "Micropaleontology," "Coccoliths," "Silicoflagellates," "Protista," and "Tintinnina."

Edward A. Horvath has completed his master's thesis on the fusulinid zones of the Permian Naco formation of Arizona and is currently employed by the Standard Oil Company of Texas in Midland, Texas. Dr. John Welch, of the Department of Geology of Colorado Western College, Gunnison, completed his Ph. D. dissertation at Utah, on the "Biostratigraphy of the Pennsylvanian and Permian systems of southern Nevada." The work featured environmental interpretations and correlations based essentially on fusulinid foraminifera, corals, bryozoans, and brachiopods. Anantha P. Setty, a graduate student in micropaleontology from the University of Mysore, India, has begun his doctoral research on the Tertiary and Pleistocene diatom (nonmarine) floras of Utah, Nevada, and Idaho. His preliminary investigations have revealed a prolific and varied sequence of diatom zones in the intermountain lake beds. Another doctoral candidate, Dwayne D. Stone, is continuing his research on the conodont faunas of the Pennsylvanian formations of the Paradox basin.

BRIGHAM YOUNG UNIVERSITY

Harold J. Bissell is sectioning thousands of Pennsylvanian-Permian samples and is building a large collection of fusulinids. This is part of a long-term project concerning the Upper Paleozoic of the Great Basin. Keith Rigby has just returned from 18 months in British Columbia and has begun another long-term project, concerning Permian fusulinids from British Columbia. David L. Clark is working on Devonian-Mississippian-Pennsylvanian and Permian conodonts, for which he has received a Brigham Young University Research Grant. Dr. Bernard Mamet, of Brussels and Berkeley, spent several days studying the Mississippian endothyrids in the University repository.

Graduate student research in micropaleontology includes the following topics: Max G. Pitcher, "Fusulinids of the Cache Creek group, Stikine River area, Cassiar District, British Columbia, Canada" (Research Studies, Geol. Ser., vol. 7, no. 7, 1960); M. L. Slade is investigating fusulinids of the Permian-Pennsylvanian of Ferguson Mountain, Elko County, Nevada. Ken Hodgkinson has work in progress on the Permian stratigraphy of northeastern Nevada. Gerald Robinson is studying the Permian stratigraphy and fusulinids of the Pequop Mountains, Elko County, Nevada. Gary Beach is investigating Upper Devonian-Lower Mississippian microfossils from central Utah.

UNIVERSITY OF WYOMING

Eugene J. Prochaska completed his master's thesis last April, on "Foraminifera from two sections of the Cody shale in Fremont and Teton Counties, Wyoming." In his study of this Upper Cretaceous shale material, Prochaska identified 61 species, 44 of which are not mentioned in the published literature on the Cody shale. Prochaska found that the foraminiferal assemblages change within short distances both vertically and horizontally in this formation. The changes include both the number of individuals and the number of species. He was unable to recognize any of the foraminiferal zones that have been established elsewhere in the Niobrara

formation. Another master's thesis on the foraminifera of the Cody shale, by Ronald K. White, is currently in progress.

INDUSTRIAL ACTIVITY

J. G. Marks writes to say that, within the Carter Division of Humble Oil and Refining Company, J. F. Clement is continuing his biostratigraphic studies on Cretaceous foraminifera. At the Palynological Research Laboratory in Golden, Colo., Dr. Robert H. Tschudy and his staff have completed a project on Permian plant microfossils, and they are continuing work on palynological samples from all parts of the world. During the past year, the Denver Research Center of the Ohio Oil Comdany has initiated studies in palynology, with the installation of special facilities, and a study of Lower Cretaceous spores and pollen in the Denver-Julesburg basin is in progress. The palynological investigations are largely the concern of John L. Wray and E. Howard Ellis. Wray and Kenji Konishi have a paper in press describing new calcareous algae from the Upper Pennsylvanian and Lower Permian of New Mexico.

Jack Burgess of the Carter Division, Humble Oil and Refining Company, reports that their organization established a palynology laboratory in Billings, Montana, during the latter part of 1959. It is an operational rather than a research laboratory and does work for all of the Rocky Mountain region. The present setup includes one laboratory technician for sample preparation and Burgess for identification. The acid-insoluble microfossils, including spores, pollen, and microplankton, are the groups receiving most of their attention. The first year of operation was spent in establishing control material from well-dated cores and surface samples. They also were able to offer routine assistance to exploration offices in the region.

The Farmington office of Shell Oil Co. reports that the past several years have been spent in the continuation of Upper Cretaceous studies, with foraminifera used for paleoecology and correlation purposes. Gene Gregory, paleontologist of the Farmington District, has been working on this project. Fusulinids and other microfossils are also being examined in the Four Corners area by Lee Holcomb, paleontologist of the Farmington Division. Several changes in personnel have occurred: Bill Roberts has been transferred from the area; Ted Cannon and Martin Reiter left to further their studies at the University of Utah and the University of Southern California, respectively. Walter L. Moore, formerly of Gulf Oil in Roswell, New Mexico, resigned his position as stratigrapher in June. He is now with the North Dakota State Survey and on the staff of the Geology Department of the University of North Dakota.

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